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Commission of the European Communities

RADIATION PROTECTION RESEARCH AND TRAINING PROGRAMME

Evolution, achievements, perspectives

Radiation protection programme 1987-92
Post-Chernobyl actions 1988-89
APAS-COSU 1991-92

Report

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Preface

In 1990 the Commission published a report which traces the evolution of the CEC Radiation Protection Programme over its 30 years of existence and summarises the most important results of the 1985-89 Programme. Since then the Programme has made changes to both the structure of the Radiation Protection Research Programme and its distribution among subject areas. These changes, together with revisions in Programme management, have ensured greater cross-fertilization between the respective subject areas and the effective integration of inputs from the whole of the programme into risk evaluation.

The present document aims to:

- present the evolution of the Radiation Protection Programme during the period 1987-1992.

  During these six years the Programme has continued to investigate in a comprehensive way the complex problems of radiological protection research. The scientific contents of the Programme have been systematically adapted to the needs and priorities of improving radiological protection with the aim of providing a sound fundamental base for the support of the regulatory activities of the Commission. The programme has made use of multidisciplinary research with the long-term goal to assess accurately low dose radiation risks. Research contractors working in several areas of the programme are recognised as leaders in their fields and the programme is acknowledged to play an important role in radiation protection worldwide. A very good balance has been achieved both in, and between, the different subject areas of the Programme.

- give an overview of the progress made during the period 1987-1992, including the results obtained through the implementation of Post-Chernobyl actions made possible by the 1988-89 Revision of the Research Programme.

  One important change in this period was the decision to manage the programme using multi-national, multi-partner contracts from 1990. This change has proved highly successful, has been welcomed by the contractors and has led to a further integration of research between scientists working in the same field.

In 1991 seven specific projects were initiated dealing with radioecology and emergency management problems resulting from the Chernobyl accident in the three republics Belarus, The Ukraine and the Russian federation. These activities were formalised in an agreement for International Collaboration on the consequences of the Chernobyl accident between the Commission and the three republics was signed in June 1992. The projects carried out in this important action under the framework of APAS-COSU are described in this report.

This document has been written with the help of the members and experts from the Management and Coordination Advisory Committee (CGC) "Radiation Protection", who continue to provide profound and astute guidance to the programme.

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incidents and to consider the possible implications for the Basic Standards and emergency reference levels; and to advise the Commission on future actions in radiological protection (Radiation Protection in the European Community, Evaluation and suggestions, Report EUR 11449; 1988). The Committee concluded that the Chernobyl accident brought into focus certain areas where research should be intensified in order to evaluate the radiological consequences of the accident and to improve preparedness for possible future accidents. This prompted the launching of 10 Post-Chernobyl Actions focusing on the assessment of the consequences of the accident and on preparedness for possible future accidents. However, the administrative procedures which have to be followed to establish extra funding and to negotiate additional research contracts essentially act as a hindrance when the programme needs to react rapidly to respond to an urgent research problem.

This evaluation document is divided into two parts; The first part deals with the overall quality of results, the management of the Programme and the consistency with Community policies and principles; the revision of Post-Chernobyl actions; the current programmes: Radiation Protection Research Action (1992-1993) and "Activités complémentaires de Préparation, d'Accompagnement et de suivi"- "Cooperation Soviet Union" (APAS-COSU); and the statistical data. The second part presents the scientific evaluation by sectors for the periods 1985-1989 (final report) and 1990-1992.

EXECUTIVE SUMMARY

The Commission's radiation protection research activities are based on the Euratom Treaty which conferred on the Community since 1957 the responsibility to establish uniform "basic standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiations and ensure that they are applied" and for the "study of the harmful effects of radiation on living organisms". The Radiation Protection Research and Training Programme has therefore essentially contributed to the continuing development of radiation protection philosophy and practices.

The Radiation Protection Research Programme is a Community research activity having a unique character as it deals with a recognized hazardous agent, ionising radiation and radioactivity, and covers the complete spectrum of complex problems from the identification of source terms, the distribution of radioactivity in the environment and the resulting exposure of the population through a quantitative and mechanistic analysis of the health effects to the continued development of risk assessment and protection policy. Radiation protection research exists because it is needed to integrate the varied contributory topics into a comprehensive and coherent entity.

The Programme has been implemented, until recently, in five-year periods via cost-shared contracts with individual institutions. The last five-year period covered 1985-1989 but then, in order to bring the Programme into synchrony with the Third Framework Programme for Community Research and Technological Development (1990-1994) a two-year period, 1990-1991 was chosen. This period heralded the introduction of multi-national, multi-partner contracts which have provided a structure for, and thus intensified, the collaboration between the different research institutions in the Programme.

A panel of independent experts evaluated the Radiation Protection Research activities over the periods 1980-1984 and 1985-1989 (Evaluation of the Radiation Protection Programmes (1980-1984 and 1985-1989), Research Evaluation Report No. 37, EUR 12145; 1989) and concluded that:

1. The Programme has reached a level of sophistication that ensures its respect from other major programmes in the world;
2. Together with the national programmes, the Commission's Programme provides people of the European Community with a sound base of knowledge and information which is essentially state-of-the-art;
3. The Programme seems, at this point, to be well balanced with respect to the distribution of activity among the subdisciplines;
4. The Programme has an excellent record of achievement in co-ordination and collaboration among scientists and their activities.

Prior to this evaluation, just after the 1986 reactor accident at Chernobyl, a "Committee of High Level Independent Scientists" was convened and asked to assess the scientific evidence arising from current research in view of recent nuclear

PART I. PROGRAMME EVOLUTION OVER THE PAST YEARS

According to the latest Evaluation Report (Evaluation of the Radiation Protection Programmes (1980-1984 and 1985-1989), Research Evaluation Report No. 37, EUR 12145; 1989), the Radiation Protection Research Programme of the Community is well balanced, leaning on multidisciplinary research with a long-term goal which is the accurate assessment of low dose radiation risks. The approach aims to derive a thorough understanding of radiation exposure and effects. In many fields, eg, microdosimetry, biophysical modelling, radioecology, radiation-induced cancer and repair mechanisms, reduction of medical diagnostic exposure, management and optimization of radiological protection and exposure to natural radioactivity, the research is "state of the art" and is acknowledged worldwide.

I.1. Performance assessment of the period 1985-1991

The Evaluation Report stated that the results of the research programme supply important information and lay down the basis for the continuing revision of the Basic Standards. The balance which has been achieved both in, and between, the different subject areas of the Programme means that the Programme's contractors are aware of the latest developments in their respective fields, in spite of the fact that reduced funding meant that some pruning of research priorities was necessary. However, the Programme remains at the forefront of development and easily adaptable to changing priorities.

Much of the work undertaken is of a pre-normative nature impinging directly on the development of radiation protection standards and on their application. This holds not only for the relevance of these results for setting European standards, but is also true at the international level. The impact of the European research effort on the activities of, eg, the International Commission on Radiological Protection (ICRP), the International Commission on Radiation Units and Measurements (ICRU), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is widely recognized. This is evidenced by the active participation of contractor groups in task forces of these international non-governmental organizations and by frequent reference to their scientific publications.

The scientific contents of the Programme have been systematically adapted to the needs and priorities of improving radiological protection. In the early Eighties, a sector on the evaluation of radiation risks and their management was added, including the risks derived from exposure to radon and its daughter products; by the mid-Eighties, more attention was given to the reduction of patient exposure in medical diagnostic radiology and to radiation effects on the developing organism, and throughout the last decade, cellular and molecular studies of radiation-induced cancer gained in importance. In the field of radioecology, the Chernobyl accident led to research in the more vulnerable natural and semi-natural ecosystems; in dosimetry, new equipment for measuring exposure is being developed and research on dosimetry of incorporated radionuclides is more emphasised and, in risk management, a strong impetus has been given to the planning of the management of nuclear emergencies and the development of decision support systems.

The present structure of the Programme covers three areas, ie:

1. Human exposure to radiation and radioactivity, with two sub-areas, namely measurement of radiation dose and its interpretation, and transfer and behaviour of radionuclides in the environment.

2. Consequences of radiation exposure to man; their assessment, prevention and treatment, with three sub-areas, namely the stochastic effects of radiation, the non-stochastic effects of radiation, and radiation effects on the developing organism.

3. Risks and management of radiation exposure, with two sub-areas, namely the assessment of human exposure and risks, and the optimization and management of radiation protection.

The recommendations put forward by the evaluation committees have almost all been implemented. Several specific items have been dealt with in the scientific coordination of the programme. A number of more general recommendations must, however, be addressed here.

While the 1985-1989 Programme was recognised to be sound, a recommendation was made that the Programme should be more adventurous and more receptive to radically new ideas. While recognised as a laudable objective, the proposal is not without its dangers and is thus being approached with caution especially in view of the insufficient level of funding for the current activities. However, strong support is being given to research which makes use of the latest techniques and "think-tank" type of meetings are being organised to advise on new research topics.

Following the 1985-1989 evaluation, changes were made to both the structure of the Radiation Protection Research Programme and its distribution among subject areas. These changes, together with revisions in Programme management, have ensured greater cross-fertilization between the respective subject areas and the effective integration of inputs from the whole of the programme into risk evaluation. Progress in more effective coordination with other CEC research programmes is being achieved. The methodological framework for comparative risk assessment, developed within the programme, is now finding a central role also within the "Joint Opportunities for Unconventional or Long Form Energy supply" (JOULE) programme and, in particular, in the major EC/US joint study of the external costs of electricity generation. Consideration is being given to how to achieve more effective coordination between two areas of central interest to both the radiation protection and "Science and Technology for Environmental Protection" (STEP) programmes - atmospheric dispersion and risk assessment from pollutants released to the environment. Risk assessment methodology for radioactive contaminants is at a mature stage of development and application of this "technology" and experience to other areas would be cost-effective and complementary. The Radiation Protection Research Programme is also actively collaborating with the programme "Europe Against Cancer" in the field of breast cancer screening by mammography.

The continuing development of radiation protection expertise has been an important aim of the Radiation Protection Research and Training Programme since the beginning. However, radiation protection research developed intensively in the late 1950's and early 1960's and the most experienced scientists are now reaching retirement age at the time when the decrease in available funding is likely to jeopardise the maintenance of high level expertise in radiation protection practice and research in the Community. Furthermore, the variations in the level of expertise which currently exist between the different Member States need to be made more balanced, especially in view of the need to define European policies for nuclear emergency management. The efforts in addressing the problem of training have therefore been increased and, following the recommendation, a specific training committee has been created. Members of this committee have been chosen from the Management and Coordination Advisory Committee "Radiation Protection" (CGC) and from the staff of DG XII-F-6 (previously DG XII-D-3) and DG XI-A-1. The committee advises the Commission on education and training activities including appropriate subjects and target groups and monitors the choice of proposed training courses and their organisation and success. The Commission's services have concentrated their efforts under the heading "European Radiation Protection Education and Training" (ERPET), and collaboration has been established in this respect with international scientific cooperative groups "European Late Effects Project Group" (EULEP), "International Union of Radioecologists" (IUR), and the "European Dosimetry Group" (EURADOS). The activities include organisation of training courses, development and provision of information and training packages, fellowships for the exchange of scientists, and promotion of the participation of young scientists in scientific conferences. The possibility of participating in the organisation of a University M.Sc. course on radiobiology is being examined. Twenty training courses were organised during the 1990-1992 period. They covered a wide range of topics and attracted approximately 600 participants.

The socio-economic impact of radiation protection research is reflected in the need to know more about the influence that radiation has on health and to understand and quantify the risk it presents to the population. There is no doubt that the Programme has had a substantial socio-economic effect - a view shared by the panel which evaluated the 1985-1989 Programme. The Programme provides a strong impetus to the development of national activities in radiation protection and enables the best use to be made of national resources. The population of the Community as a whole is exposed to a variety of radiation sources, such as medical X-rays, radon in homes, and nuclear installations, and applications of radiation for the benefit of society continue to increase. The aim of radiation protection research is the improved health protection of those who are at risk of being exposed and most of the socio-economic effect has been on the health status of the population, either directly through the Programme or indirectly from medical spin-offs and its input to regulations. Indeed, as we know, all industry is obliged by society to be responsible for the protection of their employees, the general public and the environment. This is true for radiation and radioactivity hazards, just as it is for other pollutants. The Radiation Protection Research Programme is providing input to the regulations which define the protection measures which industry has to follow, and is also providing the instrumentarium, such as dosimeters and

optimization methodology, by which industry can ensure that it satisfies the legal requirements. In this way, the Programme benefits industry. The Programme has also promoted more efficient use of Community resources through the development of optimisation techniques which have more general application than only in the field of radiation protection. Other important effects have been avoidance of unnecessary duplication of scientific research and the contribution to a worldwide scientific effort.

An expansion of fruitful interactions with other countries was recommended in the 1985-1989 evaluation. Over the past decade, the wider European dimension of the Programme became more apparent through the participation of EFTA scientists in many contractors meetings and workshops. This ultimately lead to Sweden becoming associated with the 1990-1991 Programme. For the 1992-1993 period, three EFTA countries, namely Sweden, Norway and Switzerland, have formally demanded full association. Preliminary contacts have been established with Austria and Finland.

The changing political situation in Eastern and Central Europe has permitted a consolidation of "sleeping contacts" with the scientific communities in these countries. For the 1992-1993 Programme period, 19 project participations are being supported in the framework of the "Pays d'Europe Centrale et Orientales" (PECO S&T Cooperation Scheme) with Czechoslovakian, Bulgarian, Polish scientists. These projects are incorporated into the Programme's existing multi-national contracts. In 1991, the Programme started several projects in collaboration with Scientific Institutions of the Republics of Belarus, Russia and Ukraine in the framework of APAS-COSU.

In an international context, significant progress has been made with the renewal of Memoranda of Understanding with Canada and the US Department of Energy (DOE) which are at an advanced stage of negotiation. An exchange of letters between the Commission and the Radiation Effects Research Foundation (RERF) in Japan will consolidate the existing collaboration. Interaction with international agencies has also been intensified, in particular with the International Atomic Energy Agency (IAEA) and the Nuclear Energy Agency (NEA) of the Organisation for Economical Cooperation and Development (OECD). Major collaborative programmes with the US include a joint EC/US study of the uncertainty associated with the prediction of the consequences of accidental releases of radioactive material and participation in an evaluation of models for predicting atmospheric dispersion in complex terrain. It also includes the integration of the CEC and US radon research programmes through common programme evaluation panels and through the creation of two DOE/CEC working groups, one on radon risk assessment and a second one on residential radon epidemiology. CEC and DOE continue to organise jointly international scientific conferences in order to improve transfer of information and to stimulate collaboration. Collaborative programmes with international agencies include a joint NEA/CEC Benchmark Exercise on Probabilistic Accident Consequence Models and joint IAEA/CEC coordinated research on VAMP (Validation and Model Performance). Close cooperation with the IAEA Coordinated Research Programmes on "Radon in the Human Environment" and "Radiation doses

in Diagnostic Radiology" has also been established.

A wide dissemination of the results arising from the Radiation Protection Research Programme is achieved by a variety of means which include the publication of the research results in scientific journals; the publication of the proceedings of meetings organized by the Programme; the distribution of the annual and final reports arising from the contracts; and by making the software packages arising as a product from the contracts available to all interested parties. The scientific work within the Programme has yielded approximately 700 publications per year (in the years 1985-1989), of which a major fraction of about 60% appeared in refereed scientific journals, the rest in conference proceedings and in other reports. The publications are widely cited, for example in the UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) reports. The staff of the Programme are aware that an essential obligation of all EC research activities is the dissemination of the results and are alert to every possibility to improve this.

I.2. Management and cost-effectiveness

Management of the Programme is done in a continuing close collaboration between the Management and Coordination Advisory Committee "Radiation Protection" (CGC-10) and the Commission's staff. In selecting contracts for the 1985-1989 Programme following the call for proposals, a preliminary evaluation was made by the national representatives and by the Commission's services, the results were pooled and used during the plenary session of the CGC for the final choice. This call for proposals yielded 554 submissions containing 774 projects. The existing selection procedure was considered to be not completely optimal and therefore a different selection procedure was adopted for the 1990-1991 programme period. After the preliminary evaluation by the national representatives and the Commission's services, three parallel working group sessions were organized to deal with 6 specific topics, namely:

1. Measurement of radiation dose and its interpretation
2. Reduction of patient exposure in medical diagnostic radiology
3. Transfer and behaviour of natural and artificial radionuclides in the environment
4. Biological effects of exposure to ionizing radiation, ie, microdosimetry, stochastic and non-stochastic effects, and effects on the developing organism
5. Assessment of human exposure and optimization of radiological protection
6. Epidemiology of exposed populations.

The working groups were asked to give due attention to the following selection criteria:

- expertise should be maintained over the entire range of subjects, implying an equilibrium between the subject areas;
- funds should be spread reasonably between research institutions, national laboratories, universities and, possibly, the private sector;

- a balance between Member States should be reached allowing fair development and maintenance of knowledge and expertise in all Member States;
- the project should have a European dimension and not just be of national interest.

The discussions in the working groups allowed a broader and deeper evaluation of the scientific merits of the proposals. It also benefitted the establishment of more efficient multi-national contractor groups by the regrouping of the proposals. The outcome of the discussions of the working groups were presented to the plenary CGC and the Commission's services then drew up a proposal with selected projects and proposed level of EC funding.

All currently accepted proposals are thus grouped in multi-national contracts, essentially the only exceptions are contracts with non-governmental international organisations ICRP, ICRU and with scientific collaborative groups EULEP, IUR, and EURADOS.

The overwhelming response of the scientific community to the call for proposals and the too limited resources available to the Programme are the major factors which contribute to the fact that the support given to each sub-project is too small (the average is at present about 50 KECU for two years). This amount should at least be doubled in order to avoid the Community support being marginalized. A serious criticism that has arisen concerns the increased bureaucracy, caused by new administrative procedures, which is perceived to be totally out of proportion with the low level of funding.

The reduction in funding for the 1985-1989 Programme was substantial and the future of radiation protection research in the Community has therefore been severely compromised. The funds available for the years 1990-1991 corresponded only to 50% of the 1985-1989 Commission research activities and the gap in contract support which occurred between the end of the 1985-1989 programme and the start of the 1990-1991 programme had consequences for the continuity of the research especially in university departments, but also in larger research institutes. Young scientists are often employed in radiation protection research solely on the basis of these contracts and when support falls away their employment and career development are jeopardized.

The second framework programme 1987-1991 was evaluated by the CGC-10 at its meeting of June 22, 1992. The Evaluation Report stated that the cost-effectiveness of the contractual research is good. This was endorsed by all CGC representatives during the latest evaluation of progress and final reports. The cost-effectiveness was further improved by the introduction of the multi-national contracts. Overall overhead expenses charged to the Programme, however, are unacceptably high: over 30% of the staff costs are for staff working for the benefit of other programmes, and the Programme's contribution to horizontal actions is unequitable for the period 1992-1993, staff costs and administrative costs exceeding the appropriations made in the Council Decision (O.J. L 336/42 of 7.12.1991).

The implementation through shared-cost contracts is believed to be fully appropriate. Adequate scientific management led to full coherence of the research, and the accompanying measures in the field of, eg, training and dissemination of results significantly contribute to the cost-effectiveness.

I.3. Consistency with Community policies and principles

The most important aim of the Programme is to ensure high quality research which is totally complementary to, and not duplicative of, work carried out in the Member States. In this way a synergy is created between the different pockets of national expertise in the multi-disciplinary topics which form the priority areas of the Programme. The results of this research are an essential input for the continuing revision of the Basic Standards and for the improvement in the protection of the population and the environment against exposure to ionizing radiation throughout the Community.

To fulfil Community policy objectives, selection criteria are applied in order to achieve:

- complementarity of the research to the national programmes and extension of their scope;
- coherence between the different scientific disciplines working on a specific topic;
- harmonization of experimental and theoretical methodologies throughout the Community;
- a unified approach to radiation protection and risk assessment;
- integration of scientists from different Member States in order to strengthen certain national weaknesses which reflect social and economic differences.

The cost-shared approach is the best way to guarantee subsidiarity in this scientific area because, while the research is carried out at the level of the Member States, it remains complementary to the national programmes and at the same time answers the Community objectives. The "multi-national contracts" approach strengthens the collaboration achieved through the Programme, thus enhancing the synergy between the national programmes.

II. PROGRAMME REVISION 1985-1989: POST-CHERNOBYL ACTIONS

The nuclear reactor accident at Chernobyl which took place on 26 April 1986, resulted in widespread radioactive contamination over large areas of Belarus, Russia, Ukraine and, to a lesser extent, the Baltic countries and the rest of Europe. Following the accident the Commission's Radiation Protection Research Programme has defined additional research requirements, re-oriented some existing research contracts and started some new contracts. This proposal for a research programme was issued by the Commission in November 1986. It also asked for a revision of the 1985-1989 Programme to deal with urgent issues. The revision was approved in October 1987, and mainly consisted in the addition of ten scientific post-Chernobyl activities, namely:

Action I: *Evaluation of data on the transfer of radionuclides in the food chain.* Four major research areas were considered: impact of chemical speciation on the radionuclide transfer in terrestrial ecosystems, especially in soils and plants; soil-to-plant and plant-to-animal transfer factors in semi-natural and agricultural ecosystems; transfer in aquatic systems and their importance for the contamination of the food chain.

Action II: *Improvement of reliable long-distance atmospheric transport models.* The objective was to examine the ability to model the dispersion and deposition of pollutants released to atmosphere as they are transported over long distances by the wind, with the overall aim of enhancing the usefulness of long-range atmospheric dispersion models in accident situations.

Action III: *Radiological aspects of nuclear accident scenarios, A. Real-time emergency response systems, B. The RADE-AID system.* A. As part of the post-Chernobyl programme, the need was recognised for improved capabilities for the real-time assessment of accident consequences and emergency response systems with the final aim of working towards the provision of key components of real-time computerised support systems, embodied in software packages to be made generally available for use in European countries. B. The objective is to provide guidelines (by developing a computer system) for decisions on countermeasures to reduce the exposure of an affected population if an accidental release of radionuclides occurs.

Action IV: *Monitoring and surveillance in accident situations.* This action was considered in four categories: detection of the accident; early measurements to determine the need for countermeasures; continuing surveillance of radionuclides in the environment, in foods and in people; and research studies, to follow the behaviour of radionuclides in the environment, in foods and in people so as to improve predictive models.

Action V: *Underlying data for derived emergency reference levels.* This action is concerned with the underlying information that is required for calculating derived intervention levels (DILs) for foodstuffs.

Action VI: *Improvement of practical countermeasures against nuclear contamination in the agricultural environment.* Contamination of some rural areas in or near the site of a nuclear accident, nuclear tests or high radioactivity releases have created needs for reclamation of agricultural areas. The tasks have been to collect and elaborate the information available on direct and indirect contamination; to investigate the means for reduction of the contamination levels in the rural environment; to assess the effectiveness of the countermeasures undertaken in rural areas.

Action VII: *Improvement of practical countermeasures against nuclear contamination in the urban environment.* Countermeasures which reduce or avoid the need for evacuation or minimise the time that people have to spend away from their homes must be taken after an accident. The major task of this action was to identify those surfaces which selectively adsorb caesium fallout by direct on-site or field measurements.

Action VIII: *Improvement of practical countermeasures: preventive medication.* The aim was to study the methodology and possible consequences of the various measures used to prevent radioiodine damage to the thyroid of populations after a nuclear accident in order to propose guidelines for public health authorities.

Action IX: *Treatment and biological dosimetry of exposed persons.* The objectives were the analysis of the effects of high dose radiation exposure (analysis of the acute Chernobyl cases), the treatment of its consequences, and their prognosis. Techniques were studied for the improvement of biological dosimetry in highly exposed persons and to determine the usefulness of cytological measurements in the case of non uniform exposures.

Action X: *Feasibility of studies on health effects in Western Europe due to the reactor accident at Chernobyl.* A report has been prepared by a task group and reviewed by an International Panel. The aim of the report is to review the radiation exposure of the Community population to internal and external radiation arising from the radioactive contamination and to advise the Commission on the likelihood of any detectable health consequences of the accident in the Memeber States and define future research to investigate the health effects.

The evaluation of the ten actions is given in Part II of this document within each sector.

III. CURRENT PROGRAMMES

III.1. "Radiation Protection Research" Action (1992-1993)

The "Radiation Protection Research" Action (1992-1993) represents a continuation and evolution of the Radiation Protection Research and Training Programme 1990-1991. It aims by means of a co-operative European research effort based on cost-shared contracts, training activities and dissemination of knowledge to provide:

1. The scientific knowledge needed to assess the carcinogenic and genetic risks to workers and the general public from exposure to low doses and low dose rates of radiation of different quality arising from natural radiation, medical diagnostic radiology and nuclear industries,

2. The methods to assess risks from radiation accidents as well as the rationales and techniques for implementation of countermeasures to reduce doses to man or to treat radiation accident victims,

3. The information necessary to expand radiation protection concepts and practices in response to demands created, for example, by innovative applications of radiation in medicine and industry,

4. The objective scientific background to help the relevant national authorities reach rational decisions on the operation of the nuclear industry, on the development of environmental criteria for radioactivity, on the management of rare emergency situations, and on the objective information to be given to the public about radiation risks and benefits,

5. The incentive and the support for co-operation between scientists and research institutions from the different Member States as well as with the EFTA and the Central and Eastern European countries for the advanced training necessary to maintain competence within the Community, and for exchange of information among scientists and with regulating authorities.

The Action "Radiation Protection Research" has been formulated as a comprehensive and balanced research approach which is made up of three basic elements: a. The definition of the sources, pathways and circumstances under which exposure occurs including the determination of the characteristics and extent of such exposure; b. The study and elucidation of mechanisms leading to radiation damage, and the quantitative assessment and prevention of the health consequences of exposure, particularly from low dose rates, and c. The assessment of the risks of radiation from natural, medical and industrial exposure in the context of other risks and their management, under normal and emergency conditions, in the framework of a general risk management policy. The work programme covers the same three research areas, as the 1990-1991 Programme. For the 1992-1993 Programme, three EFTA countries, namely Sweden, Norway and Switzerland, have formally demanded full association with the Programme.

The budget accorded for the 1992-1993 period shows a further decrease from that of the 1990-1991 period and is now at a level such that serious consideration will need to be given to the exclusion of some of the topics addressed in the programme. Thus, unless the funding level is improved in the next period, the coherence and comprehensiveness of the programme will be seriously affected. The Evaluation Panel had already pointed out in 1989 that the funding was inadequate.

In order to maintain a steady and rapid flow of information exchange, the ""Radiation Protection Research" Action is continuing for the programme 1992-1993 to organize study group meetings among contractors, as well as international workshops and seminars. Workshops and seminars are often co-organized with contractors from Member States and/or with institutions from US department of Energy, Atomic Energy of Canada Limited, Radiation Effects Research Foundation, Hiroshima. Central European and Eastern countries are increasingly considered to be active participants in such meetings.

For education and training actions, emphasis is placed in this 1992-1993 programme on the introduction and extension of training programmes which are adapted to several levels of knowledge and to various target groups. However, budgetary limitations will enable only a part of the planned actions to be pursued.

The co-operative groups initiated in the past, such as EULEP, EURADOS, and IUR continue to promote technical co-operation among contractors and non-contractors within the Community as well as Central and Eastern European countries.

III.2. APAS-COSU (1991-1992)

In the Communication of the Commission to the Council (SEC(91)220 DEF, 12.02.91) the collaboration with the Chernobyl Centre for International Research (CHECIR) was launched. This happened early '91, at a time at when the CHECIR centre was created by the All-Union Ministry for Atomic Power and Industry. By the end of '91, CHECIR became a Ukrainian institution and lost the All-Union support. Consequently, the Agreement for International Collaboration was signed with the authorities of the three republics, Belarus, Russia and the Ukraine.

This programme is financed in the frame of an APAS - Nuclear Fission Safety. The Agreement for International Collaboration on the Consequences of the Chernobyl accident between the Commission and the three republics was signed in June 1992. Within the terms of this agreement a Co-ordination Board has been established with representation from the Commission and each of the three republics. The Coordination Board has a number of roles including oversight of the programme, choice of projects, coordinators and participating institutes.

In the first period (1991-1992) a series of five Experimental Collaboration Projects (ECP) on environmental issues and two Joint Study Projects (JSP) on emergency management have been initiated. These projects are now being continued in 1992-1993, and enlarged following a call for tenders. In order to carry out the research, European projects groups (consortia) have been composed which are working very

closely together with scientists from the three republics, under the supervision of the competent Coordination Board. In 1992 three additional projects on the Health consequences of the Chernobyl accident were launched.

Main objectives of the projects

ECP'S on environmental issues

ECP 1: "Contamination of surfaces by resuspended material"

The aim is to predict airborne contamination levels and levels of deposition onto urban and rural surfaces by material resuspended by natural and man-made phenomena; and to assess the significance of resuspension in terms of re-distributing material from areas of higher to lower levels of contamination, in particular the implications of this for decontamination policy.

ECP 2: "The Transfer of radionuclides through the terrestrial environment to agricultural products and livestock, including the evaluation of agro-chemical practices"

The project is studying the soil-plant transfer problems: migration, mobilisation/immobilisation and availability of radionuclides in different soil systems, transfer of radionuclides to and within plants, including rain splash and resuspension, influence of agricultural practices on the transfer of radionuclides from soil to plant. It also started to study the transfer of radionuclides to livestock, off-spring and agricultural products. Descriptive models, with sufficient generality and flexibility, of the different soil-plant-animal systems are being developed.

ECP 3: "Modelling and study of the mechanisms of the transfer of radioactive material from the terrestrial ecosystems to and in water bodies"

The objective is to measure the hydraulic flow rates and the remobilisation of radioactivity within catchments, lake sediments and in the water column of freshwater systems. The transfer of radiocontaminants to fish is correlated to their food, their metabolism and the impact of ages. Modelling and testing of models describing the transport from catchments and transport in the water column and transfer to fish is performed.

ECP 4: "Evaluation and development of decontamination strategies for a range of environmental situations and evaluations of their efficacy and other impacts"

For urban decontamination clays, wet sandblasting, ammonium nitrate solution, high-pressure waterstream were all tested for walls and roof decontamination. Numerous measurements concerning the distribution of the deposited radioactive materials (roofs, walls, roads, lawns,...) are being carried out to permit the calculation of the dose rate coming from the different sources and hence to determine which surfaces should be decontaminated to achieve the most effective to

dose reduction. Soil decontamination trials removing the vegetal carpet at Bouryakovka and at Chiistaglova (both in the 30 km area), and trials of decontamination of the organic waste obtained from the vegetal carpet by biodegradation are being performed to deal with forest decontamination. Different techniques to use radioactive timber are being developed. Most of them are using thermal processes to produce liquid or gas as an energy source in a heat power plant so that all the radioactive contamination remains in the ash. Food decontamination trials with emphasis on milk and meat are being performed. Since 1986, decontamination strategies are being carried out in 35 different locations of the CIS and a precise cartography of the 30 km area is to be drawn.

ECP 5: "The behaviour of radionuclides in natural and semi-natural ecosystems (forests, marshes, heather, etc.)"

The aim is the study of the long-term behaviour of radiocesium in semi-natural ecosystems. This includes the determination of the ecological half-life and prediction of contamination levels in these areas on a long term basis; the study of the influence of the deposition mode and of soil characteristics on the migration behaviour of cesium in soil and on the resulting external exposure; an investigation of the radionuclide cycle in forest soil-plant systems and the role of forest litter on migration, mobility and availability. Transfer of radionuclides from meadow (pastures) soil to plant, and to wild animals are also being studied.

JSP'S on emergency management

JSP 1: "Real-time on-line decision support systems for off-site emergency management following a nuclear accident"

The objective is to improve the models included in Decision Support Systems (DSS) for off site emergency management adding additional models to make the systems more comprehensive. The RODOS system, being developed within the framework of the Radiation Protection Research programme, is being used as a platform for this work and its application will be broadened to the CIS countries. The data obtained following the Chernobyl accident will be used both to improve and validate models in the DSS.

JSP 2: "Development and application of techniques to establish intervention levels for use in nuclear accidents"

The aim is to develop a more coherent and rational framework for establishing intervention levels for use in response to future accidents.

Health-related projects

ECP 6: "Biological Dosimetry including Cytogenetics"

The objective is to quantify exposure of irradiated persons. This will be studied by using the relatively new method of fluorescence in situ hybridisation (FISH) to

analyze stable chromosomal damage in lymphocytes and assess its applicability for the determination of cumulative radiation dose. The assay will be used on selected irradiated persons. A teaching/technology transfer primarily from west to east will be established. There will be close collaboration between ECP6 and ECP7.

ECP 7: "Epidemiological investigations including dose assessment and dose reconstruction"

At a first stage a detailed questionnaire concerning, for each state, existence, contents, sources of information, completeness, centralization and computerization of cancer registries, population registries (death, residence) and "Chernobyl registries" will be developed. During the same period the documentation of the reported increase in thyroid carcinoma in children in Belarus, and the planning of pilot investigations as needed will be established. Sources of information for the construction of cohorts of liquidators in each state (Chernobyl registries, military records ...) will be identified and protocols to study the leukaemia risk in liquidators and if judged feasible and desirable for other studies will be outlined. Training activities: a short course in basic cancer and radiation epidemiology, focusing on specific needs of the three states, will be held in the CIS.

JSP 3: "Treatment of accident victims"

The aim is the establishment of a joint study of the acute effects of high dose accidental irradiation, in particular (i) evaluation of patients treated for acute radiation sickness after the accident, (ii) damage to the immuno-hemopoietic system, which belongs to the most radiation sensitive systemic organs, and (iii) the skin. Of 237 patients suffering from acute radiation sickness, 209 survived and are in the process of rehabilitation. It is proposed to use this wealth of patient material for an in-depth investigation on acute as well as late radiation damage in different organs. This part of the project aims to establish dose-effect relationships for various types of organ damage.

IV. STATISTICAL INFORMATION

Inputs

The statistical breakdown has been done for three periods:

1. the 1985-1989 statistical data
2. the 1990-1991 statistical data
3. the 1992-1993 statistical data

It is important to note that during this time span, the structure of the Programme was modified.

For the 1985-1989 period, the sectors were categorized as:

A. Radiation dosimetry and its interpretation
B. Behaviour and control of radionuclides in the environment
C. Non-stochastic effects of radiation
D. Radiation carcinogenesis
E. Genetic effects of radiation
F. Evaluation of risks and optimization of radiation protection.

Contracts were signed with individual institutions only, but could contain several sub-projects. Overall coordination was achieved through the organization of contractors' meetings.

For the 1990-1991 and 1992-1993 periods, the subject areas are categorized as follows:

I. Human exposure to radiation and radioactivity
   - I.1. Measurement of radiation dose and its interpretation
   - I.2. Transfer and behaviour of radionuclides in the environment

II. Consequences of radiation exposure to man; their assessment, prevention and treatment
   - II.1. Stochastic effects of radiation
   - II.2. Non-stochastic effects of radiation
   - II.3. Radiation effects on the developing organism

III. Risk and management of radiation exposure
   - III.1. Assessment of human exposure and risks
   - III.2. Optimization and management of radiation protection.

For these periods, newly submitted proposals were based on the multi-national, multi-partner contract format. Some individual contracts of the previous period were extended, but, wherever possible, were regrouped into a multi-partner contract or merged with a multi-national project.

For the three periods under consideration, statistical data are presented in Table 1 on: proposals; accepted projects and sub-projects; cost of research and EC support; and the distribution of sub-projects over research organisations, universities and other organizations. Due to the budgetary constraints, the average participation of the EC in the total cost of the research went down from 44% during the 1985-89 period to 28% during the 1990-1991 period and to 26% during the 1992-1993 period. The distribution of sub-projects over research organisations, universities and others remained fairly constant. However, a tendency to more intensive participation of universities is undeniable. This policy of trying to support a maximum of projects was inspired by the wish to maintain a comprehensive research effort and to consolidate previous efforts in all fields of radiation protection.

The distribution of resources by sectors is given for 1985-1989; 1990-1991; and 1992-1993, in figure 1. The distribution for the 1985-1989 period takes account of the 1987 revision of the Programme, i.e. the launching of 10 Post-Chernobyl Actions (R). The support towards the different sectors of the Programme during this period kept in line with the previous Programmes, though with a slight shift of resources towards "Evaluation of Radiation Risks and Optimization of Protection". The resource allocation per subject area for the 1990-1991 period i.e. Radioecology (I.2.) and Risk Evaluation and Management (III.1. and III.2.) were awarded a slightly higher share, whereas the Biological Areas received somewhat less than in the preceding period. The resources allocated to the International Organizations (IO) is also shown in the figure. For the 1992-1993 period, there is a slight increase for the stochastic effects (II.1), with a decrease for non-stochastic effects (II.2), the other subject areas remaining rather constant. An increase is observed for the resources allocated to the I.O..

Figure 2 shows the distribution of projects over the Member States for the three periods. The overall picture of distribution between the Member States remains almost the same even if the number of projects decreases from 440 (1985-1989) to 325 for the period 1990-1991. A slight increase is observed during the 1992-1993 period (367 projects).

The 1990-1991 period was characterized by the introduction of multi-national contracts. Figure 3 indicates the number of partners within the multi-national projects for the 1990-1991 and 1992-1993 periods. This distribution indicates a trend towards more partners in the projects which are usually from different Member States or associated countries.

Outputs

The most important output indicators of this analysis are depicted in figures 2 and 3. These figures indicate a real European dimension of the projects, both through the number of projects in each country and through the number of partners per project. This is an illustration of the multi-disciplinary character of the research and gives full evidence of the strong subsidiarity of the Programme.

Radiation Protection Research, by its very nature, is not a subject to be entrusted to a limited number of huge research organizations. The many aspects of importance, some dictated by socio-cultural and economical considerations, have to be considered in order to avoid the dominance of a single philosophy and to maintain a flexible approach. The cost-shared contracts have proved an excellent tool for reaching that objective.

The limited resources made available for radiation protection research since the late eighties seriously jeopardize the future comprehensiveness and coherence of the Programme. There is low monetary value of the multinational projects with an average 5 partners, and thus a low support per partner (around 50.000 ECU in 1992-1993). This will lead to full marginalization of the EC support and a loss of motivation of the partners in the research to comply with the EC objectives. This will threaten the subsidiarity of the Programme and already results in a decrease of expertise in several Member States. It is hoped that this situation will improve during the Fourth Framework Programme.

APAS-COSU

In the frame of the APAS-COSU, a preparatory phase of 7 projects, dealing with radioecology and nuclear emergency management, was launched in 1991.

This programme is financed in the frame of an APAS - Nuclear Fission Safety. The budget was 3 MECU in 1991 and 7 MECU in 1992, of which 2.3 and 4.7 MECU respectively for Radiation Protection (contracts and overhead expenses) (figure 4).

In 1992, an "Agreement for International Collaboration on the Consequences of the Chernobyl Accident" between the Commission and the republics of Belarus, Russia and Ukraine was signed. Following a call for proposals, the 7 projects were extended, and at present 7 multinational teams (with the participation of 45 European research groups) collaborate with multi-state teams from the 3 republics. Also in 1992, 3 additional projects dealing with the medium-term health consequences of the accident were launched (figure 5). It is now becoming evident that studies have to be implemented to finalize the medium-term assessments and prepare the evaluation of the long-term consequences.

TABLE 1: NUMERICAL STATISTICAL DATA

	Programme Period		
	1985-1989	1990-1991	1992-1993
Total number of proposals	554	333	192
with number of sub-projects	774	835	683
Total cost of proposed research (MECU)	346	164	123.4
Requested EC contribution (MECU)	135	101	71.4
Total number of projects accepted	359	137	112
with number of sub-projects	453	347	428
Total cost of accepted research (MECU)	120	76	85.6
EC contribution given (MECU)	52.4	21.1	21.9
Total number of contracts *	336	64	76
% of sub-projects entrusted to research organizations	72.3	73.3	65
% of sub-projects entrusted to universities	24.5	26.7	33.7
% of sub-projects entrusted to other organizations **	3.2	-	1.3

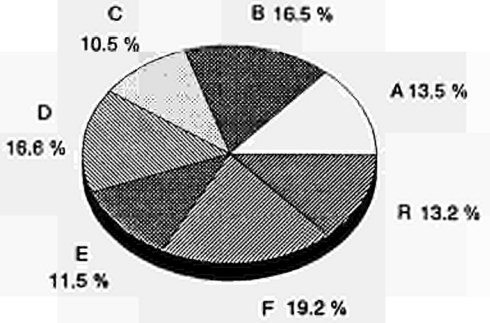
* Without study contracts (9 in 1985-1989 and 11 in 1990-1991)

** It is worth mentioning that many departments of research organisations, hospitals and universities are managed and run as SMEs. The situation is, however, rather unclear and these contracts are counted under the above-mentioned categories.

Figure I

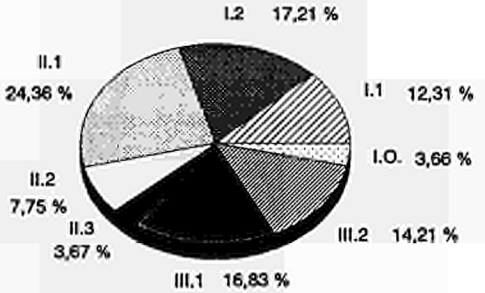
Distribution by Sectors, Subject Areas

1985 - 1989



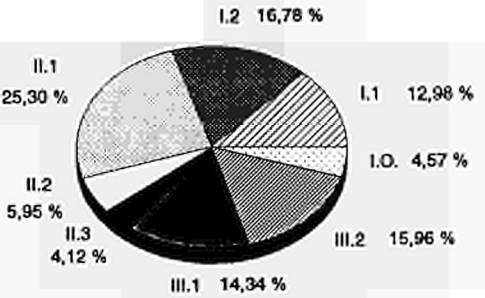
Distribution by Sectors

1990 - 1991



Distribution by Subject Areas

1992 - 1993



Distribution by Subject Areas

Figure 2

Distribution of projects over the Member States

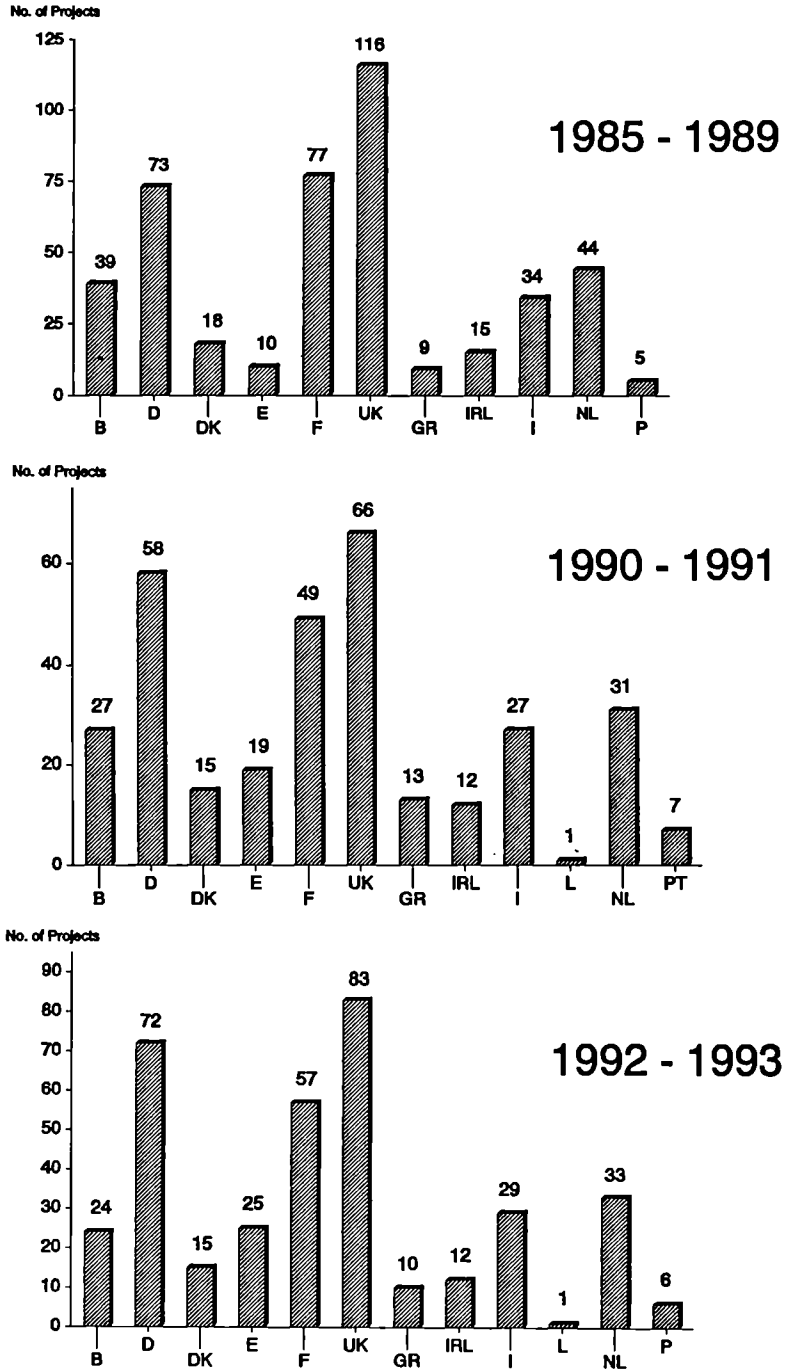
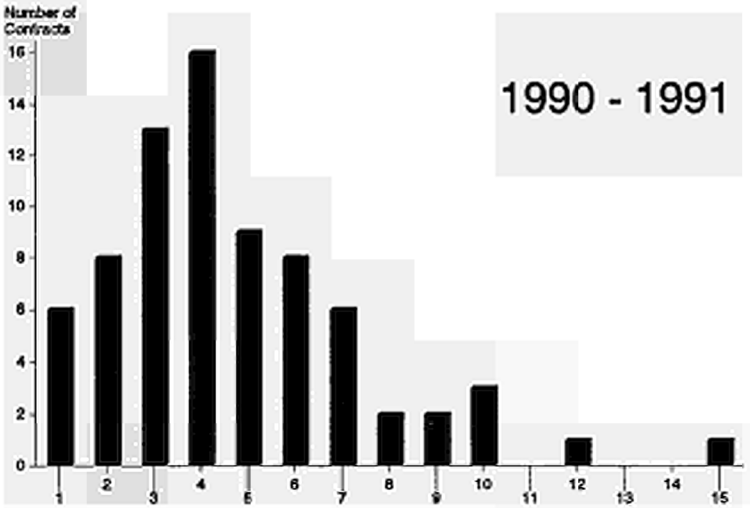


Figure 3

Number of partners per contract



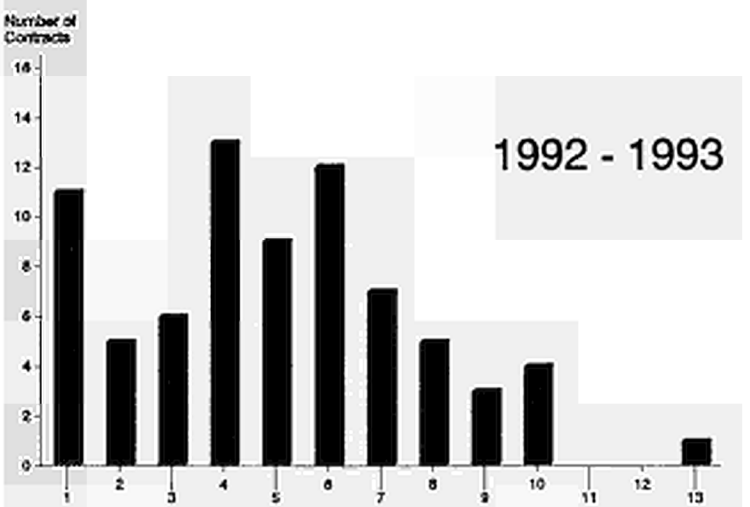
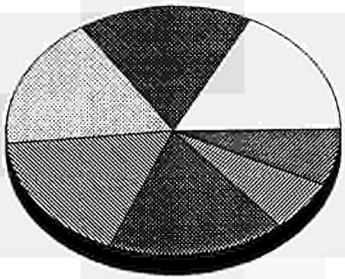


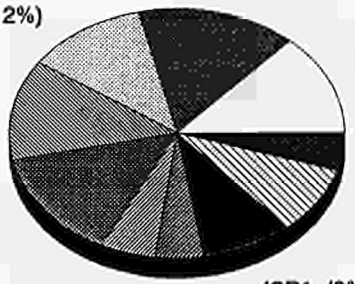
Figure 4

APAS



1991

ECP1	363	KECU
ECP2	358	KECU
ECP3	363	KECU
ECP4	363	KECU
ECP5	363	KECU
JSP1	137.2	KECU
JSP2	152.7	KECU

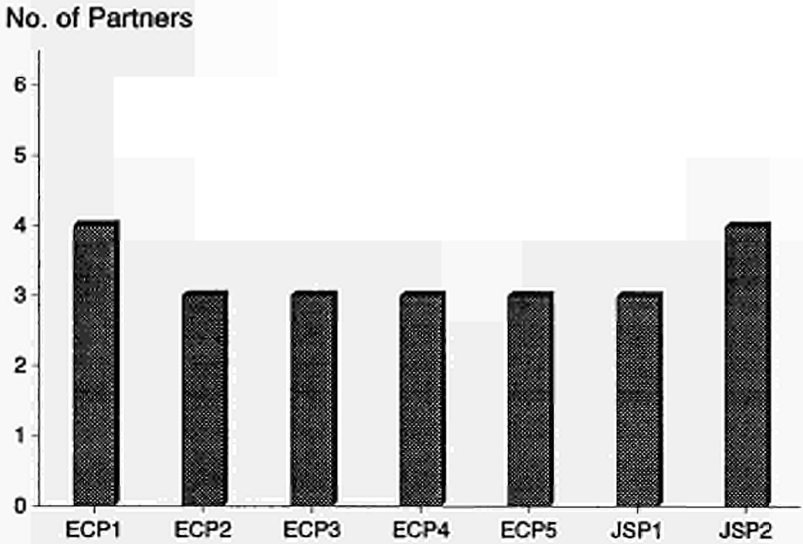


1992

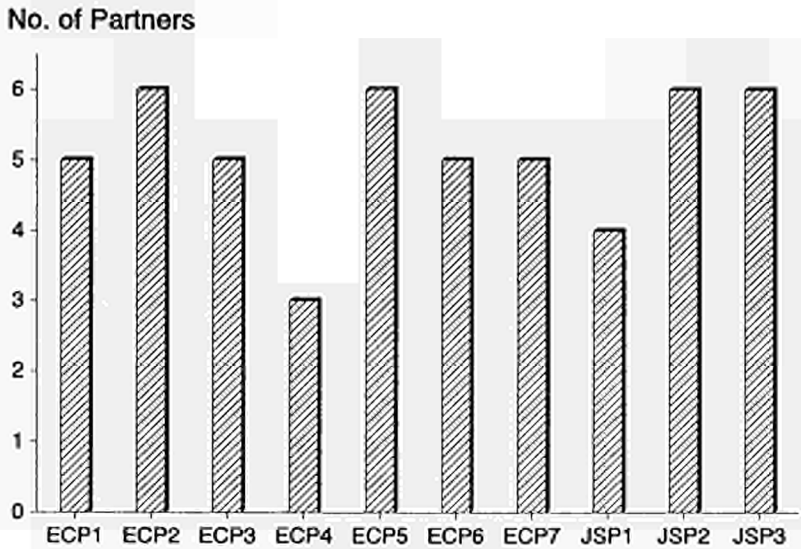
ECP1	560.5	KECU
ECP2	665.5	KECU
ECP3	495.5	KECU
ECP4	560.5	KECU
ECP5	600.5	KECU
ECP6	223	KECU
ECP7	200	KECU
JSP1	375.5	KECU
JSP2	370.5	KECU
JSP3	227	KECU

Figure 5

APAS



1991



1992

PART II. SCIENTIFIC EVALUATION

SCIENTIFIC EVALUATION

SECTORS

I. MEASUREMENT OF RADIATION DOSE AND ITS INTERPRETATION

II. RADIOECOLOGY

III. CONSEQUENCES OF RADIATION EXPOSURE TO MAN

IV. RISK AND MANAGEMENT OF RADIATION PROTECTION; ASSESSMENT OF HUMAN EXPOSURE AND RISKS

V. OPTIMISATION OF RADIATION PROTECTION IN MEDICINE

VI. EDUCATION AND TRAINING IN RADIATION PROTECTION (ERPET)

I. MEASUREMENT OF RADIATION DOSE AND ITS INTERPRETATION

I.A. INTRODUCTION

I.B. SCIENTIFIC ACHIEVEMENTS

I.1. IMPLEMENTATION OF NEW DOSIMETRIC CONCEPTS AND QUANTITIES

I.2. INSTRUMENTATION FOR INDIVIDUAL, AREA AND ENVIRONMENTAL MONITORING

I.2.1. Area Monitoring
I.2.2. Individual Monitoring
I.2.3. Environmental Monitoring

I.3. EXPERIMENTAL AND CALCULATIONAL METHODS FOR DOSIMETRY

I.4. INTERNAL DOSIMETRY

I.5. POST-CHERNOBYL ACTION

I.6. SUPPORT TO SCIENTIFIC COLLABORATIVE GROUPS: European Radiation Dosimetry Group (EURADOS)

I.C. CONCLUSIONS AND PERSPECTIVES

I. MEASUREMENT OF RADIATION DOSE AND ITS INTERPRETATION

I.A. INTRODUCTION

Radiation dosimetry has to provide the concepts, procedures and techniques for the determination of the amount of ionising radiation delivered to tissues and organs which then can be related to the induced biological effects. In radiation protection, dosimetry is thus concerned, on one side, with fundamental aspects of radiation interaction and the relationship between physical quantities and biological effects and, on the other side, with practical aspects of developing dosimetric concepts and quantities for the establishment of limits and standards for the control of exposure of workers and the general public. Physical dosimetry is therefore involved in all radiobiological research of relevance for radiation protection and provides the quantitative basis for risk assessments and related dose limits for exposure from external and internal radiation.

International committees, such as ICRU[1] and ICRP[2] have continued to develop theoretically improved and consistent dosimetric concepts and quantities which are aimed at providing a more generally applicable and coherent basis for risk assessment and control of radiation exposure. Research work within the CEC Radiation Protection Research and Training Programme has continuously played a decisive role in providing the scientific background for this conceptual development. The practical **implementation of these dosimetric quantities and concepts** is one of the topics of the programme which involves dosimetric calculation methods and the development of operational practices. Availability of adequate **instrumentation for individual, area and environmental monitoring** is a basic prerequisite for the reliable determination of doses for external and internal exposure and for ensuring compliance with regulatory requirements. Very active work in the various aspects of this research area has been carried out both for weakly and highly penetrating external radiation. In addition to the need for developing practical instrumentation, there is also a need for basic research in (**experimental and calculational methods for dosimetry**). This type of research helps to maintain the general preparedness for optimal radiation protection practices, it provides a sufficiently high scientific level in the fields on which dosimetry (and microdosimetry) is based and it is well suited to the **training of young scientists** entering the field of radiation protection. Calculational methods play an important role in the context of the **determination of organ doses** which is of practical relevance in all exposure conditions in which the irradiation of one or several organs are predominant, such as skin in the case of weakly penetrating radiation.

Research into the metabolism and dosimetry of radionuclides (**internal dosimetry**) taken into the body occupies an important part of the programme. Improved

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[1] International Commission on Radiation Units and Measurements

[2] International Commission on Radiological Protection

instrumentation for monitoring of intakes are complemented by a steady improved knowledge of age and sex dependent metabolic pathways and of distribution of nuclides in various tissues. Metabolic-dosimetric models using the improved knowledge contribute towards establishing more reliable annual limits of intake for internal radiation exposure.

The evaluation panel of the Radiation Protection Programmes (1985-1989) made some specific recommendations for the sector "Radiation dosimetry and its interpretation" which concerned internal dosimetry, biophysical modelling, teaching and training, the implementation of new quantities and cosmic ray dosimetry. In accordance with these recommendations, the current programme has been modified compared to the 1985-1989 period.

Research effects in internal dosimetry have been increased substantially and progress is significant. In fact, scientific input into ICRP activities on internal dosimetry and development of recommendations relies strongly on research supported by the Programme. There is unfortunately no work at present on accident dosimetry due to a complete lack of proposals. Biophysical modelling is progressing rapidly and includes now initial modelling of realistic biological structures and the modelling of radiation induced molecular effects. The availability of super computers for this task has proven to be important. With the beginning of the 1990-1992 programme period, the subject area of microdosimetry and biophysical modelling has been integrated into the programme section on "Stochastic Effects of Radiation" (see below), with the intention of stimulating the interaction and collaboration of physicists and biologists in this interdisciplinary field.

Activities in teaching and training have been increased by initiating a EURADOS working group on basic data and instrumentation, which has attracted universities and post-graduate students and by organising a training course on modern methods in radiation measurements and dosimetry. The preparation of the implementation of ICRP and ICRU recommendation and the related revision of the Basic Safety Standards is very far advanced. Work on dosimetry for cosmic ray exposure in civil aviation has started.

I.B. SCIENTIFIC ACHIEVEMENTS

I.1. IMPLEMENTATION OF NEW DOSIMETRIC CONCEPTS AND QUANTITIES

The introduction of the quantity "effective dose equivalent" for the assessment of risk by ICRP in 1977 was of fundamental importance for radiation protection. It takes account of the different radiosensitivities of individual tissues and provides a measure of the risks of radiation exposure regardless of its non-uniformity. The ICRU has developed a set of operational quantities for area and individual monitoring of external irradiations which are used as estimators for effective dose equivalent, which is the basis for limiting exposures. Several contractors (mainly national laboratories), including ICRU itself, made relevant contributions to the development of this theoretically sound and widely applicable dosimetric concept and the related quantities. Computational dosimetry, the methods for which were

developed within the Programme, provided the relations between physical quantities characterising the radiation fields, operational quantities and effective dose equivalent, and has been used to estimate organ and tissue doses for external exposure and from radionuclides incorporated in the body. The applicability of the new quantities, the consequences for instrumental requirements and calibration procedures have been investigated. A workshop "Implementation of dose-equivalent operational quantities into radiation practice" organised by the CEC Radiation Protection Programme and Physikalisch-Technische Bundesanstalt (PTB) in 1988, cosponsored by ICRU, ICRP, EURADOS[3] and the US Department of Energy contributed towards achieving broad acceptance of the new quantities and accelerating their practical implementation. Specific problems, such as the suitability of various phantoms for calibrating individual dosemeters for photons and neutrons, the development of tools for realistic three-dimensional modelling of real man ("voxel phantom") and the analysis of radiation fields at workplaces (e.g. reactor environment, medical X-ray machines) are of relevance for the practical implementation of dosimetric concepts and quantities. In the current programme work dedicated to this issue is carried out in two coordinated research contracts and by a EURADOS working group. One of the contracts is concentrating on photon irradiations, the other on neutrons. In both contracts, emphasis is put on radiation field analysis and spectrometry at work places. The work is also aimed at developing calibration facilities with "realistic" radiation fields and at improved interpretation of individual dosemeters.

Partly based on recent scientific findings and, partly, due to intentions to simplify procedures and relations, ICRP has introduced in its most recent recommendations (1990) new quantities ("effective dose" to replace "effective dose equivalent" and "radiation weighting factor" to complement the "quality factor" for risk related quantities). Furthermore, it recommends to increase the risk coefficients (and, consequently, to reduce dose limits) and to increase the quality factor (for neutrons on average approximately by a factor of 2). The formerly achieved hierarchy and balance between operational and exposure limiting quantities is possibly affected by the new ICRP recommendations, at least for neutrons, and new investigations are currently underway to establish the relation between these quantities. Furthermore, the consequences for instrumental requirements, in particular individual dosemeters must be thoroughly investigated (see below).

The interaction between radiation protection research and radiation protection regulation, in particular the development of the EC basic safety standards, is clearly demonstrated in this area of the Programme. It becomes apparent, that not only is research the basis for the development of safety concepts and standards but that there are a feedback and requirements from regulatory activities to research which contribute effectively to the progress in radiation protection of workers and the general public.

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[3] European Radiation Dosimetry Group

I.2. INSTRUMENTATION FOR INDIVIDUAL, AREA AND ENVIRONMENTAL MONITORING

Research into instrumentation has attracted in relative terms the majority of research proposals in the dosimetry sector, both in 1985-89 and 1990-1992. It reflects the continuing need for improved instruments as well as the considerable Community expertise existing in this field. The anticipated changes in the recommendation of the ICRP with regard to risk coefficients, dose limits and quality factors (which finally were issued in late 1990) and, therefore, the increased demand for improved instrumentation and dosemeters was an additional motivation for work in this area. The availability of some new detector materials and modern micro-electronics has also injected new impetus into the activities in this field. The traditionally close collaboration between contractors in this area, partially stimulated by EURADOS, has further increased due to the introduction of coordinated multi-partner contracts in 1991.

I.2.1. Area monitoring

Area monitoring of work places is an important tool to implement radiation protection regulation. Whereas the remaining research problems for photons are restricted to weakly penetrating radiation there are still problems for neutrons and mixed neutron photon-fields. In particular, the energy response of conventional neutron area monitors is poor, which is of concern if there are variations of the neutron energy spectra to be expected, e.g. at different workplaces within one nuclear installation or if there are temporal changes at a given workplace. Research into the development of tissue-equivalent proportional counters (TEPC) into area monitors was carried out in close cooperation by four contractors and within a EURADOS working group in 1985-89. The extensive and comprehensive research with this type of microdosimetric detector and the accompanying technical development (miniaturisation of complex analogue and digital electronics) included an intercomparison of prototypes at reference neutron and mixed radiation fields. It was shown that TEPC area monitors can be made to have a much better energy response in terms of ambient dose equivalent than conventional instruments. In addition, the TEPC provides spectral information which have been used with advantage for radiation field analysis. Several semi-industrial TEPC prototypes have been built by groups in France, Germany and the UK and in the meantime commercial TEPC instruments are available. Since 1990, the research work in this area has been reduced to a few specific tasks within one coordinated contract, such as the optimisation of the energy response to neutrons and developments to increase the sensitivity. Recently, the TEPC has also been shown to be very suitable for dosimetry in civil aviation. Other instruments developed and investigated included a coaxial twin proportional counter, to be used for neutrons of intermediate energy, and twin proportional counters, which are operated in the so called variance-covariance technique and are of potential use in rapidly varying radiation fields as encountered at some physical and medical accelerators. Measurements near medical linear accelerators are a problem for conventional area monitors because of the pulsed structure of the beams. The variance-covariance technique has been used in prototype instruments in diagnostic X-ray fields and therapy facilities. It was shown

that this approach is also of direct use to medical problems. Furthermore, this technique was used to perform measurements of the micro-dosimetric quantity dose mean lineal energy, Y_D, for simulated diameters down to 6nm with an X-ray tube. It was shown that Y_D varies for the radiation used by a factor of 20 if the simulated diameter is varied between 6nm and a few μm. This type of application may have significance for the subject area of microdosimetry (see below). Small sized, high pressure ionisation chambers have a high sensitivity and were shown to provide information on radiation quality.

Previously developed methods for neutron and photon spectrometry have been increasingly applied operationally for the analysis of field characteristics in the workplace. The analysis of field characteristics in the workplace will be of importance in view of reduced dose limits and increased quality factors. This type of instrumentation, together with other types providing spectrometric information on radiation quality such as TEPC area monitors, will also contribute to improved individual monitoring by offering the possibility of field calibration of individual dosemeters, which mostly have a noticeable energy dependent response. In a collaborative contract, operational neutron spectrometers have been used to measure spectral neutron fluence typically encountered in practice (nuclear fuel processing, nuclear power plants, etc.). The preparation of a catalogue of all measured spectra in an agreed format has been started. One of the aims is to identify spectra which can be considered representative for working places. In a next step, these representative spectra are to be reproduced in a laboratory using neutron sources and suitable accelerators and appropriate moderating material. These "realistic" reference fields may serve for calibration of individual dosemeters and intercomparisons.

This type of work is complemented by the activities of a EURADOS working group which has been organising intercomparisons of a wide range of spectrometers and area monitors at such a reference field and at real workplaces.

In the area of area monitoring of photons, the recent development of a novel spectrometer using a sodium iodide detector, capable of giving spectral and angular distributions has shown to be a powerful tool for workplace spectrometry. One of the aims of the related coordinated research contract is finally to produce also for photons "realistic" reference radiation fields which would be a "wide" spectrum rather than the conventional monoenergetic photons used in calibrations. Radiation spectrometry is an area where advanced experimental techniques are required as well as radiation transport calculations using adequate basic physical data. Research work in this field is therefore well suited for the training of young scientists. The concrete work in this area is going to lead to the establishment of an atlas of workplace radiation fields and to improved calibration methods in realistic radiation fields.

Area monitoring for radiations with low penetrating power ("skin dosimetry") was neglected before 1980 and consequently considerable effort went into this topic. A EURADOS working group and several contractors carried out theoretical and practical studies on beta-ray and low energy photon dosimetry and identified

problem areas in occupational situations. In cooperation with a working group of EULEP (European Late Effect Project Group) research into the determination of the sensitive layers in the skin was carried out. As documented during a Workshop on Skin Dosimetry (1991), it is now established that a depth of 50 to 100 μm is appropriate for skin dose equivalent measurements. The workshop revealed also the marked progress in instrumentation for skin dosimetry. In a coordinated research contract, beta radiation calibration facilities using extended area sources, capable of irradiating instruments at different angles and distances have been developed. The extrapolation chamber technique is the fundamental dosimetry measurement technique for beta dosimetry. Because of the complexity of its mode of operation, a fully computerised measurement procedure is currently under development. As for neutrons and photons, measurements are being carried out to characterise beta radiation fields at work places, in this case in terms of the directional dose equivalent rate. The remaining problems are adequate dosimetry for body extremities and the dosimetry of so called hot particles encountered in nuclear industries.

I.2.2. Individual monitoring

The control of compliance with regulatory requirements and the estimation of doses received by individual radiation workers relies heavily on the use of individual dosemeters. The techniques and procedures of personal dosemeters play a critical role within the concept of monitoring (operational) and dose-limiting quantities. The decrease of exposure limits and, in the case of neutrons, the increase of the quality factor lead to the requirement of improved detectors, in particular with regard to their sensitivity. However, even without these changes obvious inadequacies existed for monitoring neutrons and beta-rays. Various types of detectors and their techniques of application were investigated: thermoluminescence dosimeters (TLD) for photons and beta-rays, thermally stimulated exoelectrons (TSEE) for beta-rays, track etch detectors (CR39) for neutrons and solid state electronic dosemeters for photons and neutrons.

The work on TLD and TSEE for weakly penetrating radiations has shown that good energy response can be obtained but that it is difficult to achieve adequate sensitivity. Work is continuing using new TLD materials and new read-out techniques, e.g. using laser heating. The plastic material CR39 (poly-allyl-diglycole-carbonate, PADC) has found considerable interest for use in individual dosimetry of neutrons (and radon). The main advantage over the conventional nuclear emulsion film detector is the lower neutron energy detected and a flat energy response. Research work, as part of a coordinated research project and within a EURADOS working group, focused on optimisation of etching techniques, improvement of the reproducibility and reduction of the background. Various groups investigated successfully the possibility of extending the energy range of applicability to lower energies by using radiators (air layers or polyethylene doped with ^{10}B) in front of the detector. An intercomparison for monoenergetic neutrons with energies between 75 keV and 66 MeV organised by the EURADOS working group documented the good angular and energy response. However, remaining practical problems include the large and variable background and insufficient sensitivity.

The development of active semi-conductor devices as a personal electronic dosemeter is attractive because it enables real time readout and it provides the possibility to apply the ALARA principle at the level of individual dosimetry. Whereas such instruments are already commercially available for photons, research and development for neutrons has only just started. The first results obtained show that similar problems are encountered as with other detectors in neutron individual dosimetry and that modified techniques have to be developed. At present, all methods used in neutron personal dosimetry are still unsatisfactory, a situation which will become more severe once the ICRP recommendations are practically implemented. Improvement is urgently required and currently alternative procedures using a two diode system or charged coupled semiconductor devices are investigated and may offer practical advantages in the future. Methods to be considered for a comprehensive approach are radiation field specification at work places (see above), use of improved area monitoring and combination of more than one individual neutron dosemeter.

I.2.3. Environmental monitoring

Environmental dosimetry has played a minor role in the history of the CEC Radiation Protection Research Programme. However, in 1991 a multi-national contract has started in which several instruments are investigated under various environmental conditions. The experiments include measurements at very low dose rates (in a salt mine background less than $1 nGyh^{-1}$) and in the vicinity of nuclear power plants. In the low background laboratory the principal properties of instruments and dosemeters were investigated including linearity, angle and temperature dependence and inherent background. Long term dose rate measurements around a nuclear power station in the UK were used to assess how different detector types respond to small variations of the background due to the release of ^{41}Ar plumes and to the 6MeV radiation from the ^{16}N-isotope produced by the (n,p) reaction in oxygen within the CO_2-coolant gas.

Environmental monitoring with integrating TL dosemeters were improved by introducing a new developed evaluation method based on numerical analysis of the glow curves which permitted the determination of the inherent background.

1.3. EXPERIMENTAL AND CALCULATIONAL METHODS FOR DOSIMETRY

Basic radiation research applied to the improvement and development of dosimetric methods has been essential in maintaining a high level of competence which enables Member States to have optimal radiation protection practices and implement effectively new dosimetric quantities and concepts.

Basic physical data have continued to be determined because their knowledge is required for the quantitative understanding of the processes in detectors and in biological tissue, for example for the evaluation of doses to different organs and tissues from measurements with detectors and dosemeters. However, the emphasis of this research activity has shifted from fundamental to more practical work. Basic interaction data such as kerma factors for neutrons up to 70 MeV and effective W-

values for neutrons were determined and are of direct relevance for dosimetry. Measurements to determine physical properties of charged particle tracks are essential for the interpretation of radiobiological experiments with heavy ions (microdosimetry). In a collaborative, fundamental approach towards the understanding of charge collection processes in ionisation gas devices, particularly the gas amplification in low pressure proportional counters, compilation and evaluation of basic data such as electron collision cross sections are performed. The validation of related model calculations is performed in dedicated microdosimetric measurements. This type and other basic physical work is performed by a recently established EURADOS Working Group which aims at providing basic information for the development and optimisation of gas filled cavity detectors and dosemeters.

The range of application of the main instrument in experimental microdosimetry, the low pressure proportional counter, has been extended considerably. The combination of cavity chamber principle and energy deposition spectrometry (and time-of-flight techniques in some cases) for a variety of detector materials provides a powerful tool to investigate physical interaction data and dosimetric quantities. As mentioned above, the development of experimental microdosimetric techniques into practical radiation protection instruments for area monitoring was very successful. It involved dedicated design and optimisation of detectors. More recently, promising progress has been made in the development of counters which can simulate tissue volumes of diameter considerably less than 1 μm. The 1 μm diameter has been considered a lower limit for the simulation for a long time. This limitation is being overcome by a combination of theoretical work on ionisation in gases and progress in experimental technique. (See also above for variance-covariance technique).

Correlated microdosimetric and radiobiological experiments and studies have been used to derive biological response or weighting functions. Evidence has been provided that this semi-empirical approach to quantify radiation quality may have advantages for the systematic analysis of radiobiological data which may have important implications for radiation protection (as well as high LET radiation therapy).

The availability of computational techniques and their continued development was an important factor in the process of implementing new quantities and concepts and several contractors have contributed the data required for the work of ICRU and ICRP committees. In general, computational methods for solving the radiation transport problems of photon and neutron radiations are now well developed but the task of linking these methods to a comprehensive modular system of computer programmes for the majority of radiation dosimetry problems has only been started within the framework of the programme. The calculations did reveal that improvement is still required with regard to the quality of basic atomic and nuclear data.

The use of computational techniques in dosimetric research is quite diversified and is often incorporated into projects dealing with specific aspects. A EURADOS working group on numerical dosimetry has been involved in several areas, mostly in cooperation with other groups and institutes, thus providing the computational

support requested for other research activities. The group carried out an intercomparison of unfolding codes for Bonner sphere measurements calculated radiation doses from Cs ground contamination, and is involved in work for standardising phantoms for external and internal dosimetry. The importance of this EURADOS working group for radiation protection dosimetry was documented after the publication of the recommendations in ICRP60. The urgently required extensive calculations to analyze the relationship between newly defined and existing quantities were largely coordinated by this group.

I.4. INTERNAL DOSIMETRY

Internal exposure to radionuclides by way of inhalation, ingestion and contamination of skin and wounds is a potential hazard in many working situations, and can also be relevant for the public. Regulations for concentration limits in air and level of intake under operational conditions are based on metabolic-dosimetric models. The parameters of these models and the models themselves have to be sufficiently specific to enable reliable dose assessment, and improved derivations of annual limits of intake to be made and to relate them to body burden monitoring using bioassays (excretion measurements).

During the period from 1987 to 1992, substantial progress has been made in determining relevant data and improving models. For example, the current revision of the ICRP lung model relies heavily on the data and results obtained on particle deposition and lung clearance and the complementing model development within the Programme. This type of research is of immediate importance for workers in nuclear industries and nuclear medicine as well as for the assessment of exposure and risk for radon inhalation. In a coordinated research contract, a general approach to the development and implementation of models for evaluating doses from intakes of radionuclides, by both inhalation and ingestion, is taken. The inhalation route studies include experiments designed to provide data required to improve models. Most of the work is linked to the development of ICRP models and recommendations. This area is very active and is expected to have to continue for the next few years. The intention is to revise the respiratory tract model, the report on Reference Man, on biokinetic models for individual elements in conjunction with age dependent models and others. This work is expected to lead finally to a full revision of ICRP Publication 30. Within the contract, the implications of the changes proposed in ICRP Publication 60 for doses per unit intake and annual limits of intake (ALI) were explored. Work has begun on the development of generic biokinetic models for those actinides and lanthanides for which little or no direct human information is available.

A study, using a stable isotope tracer technique, of the metabolism of various nuclides such as Te, Sr, Ru, Zr, Pu and other actinides has started in 1991 and has made significant progress. This elegant and promising approach is expected to provide relevant data for the improvement of metabolic models. Several analytical techniques, such as proton nuclear activation analysis (PNA), inductively coupled plasma mass spectometry (ICP-MS) and graphite furnace atomic absorption (GFAAS) have been successfully used and first results obtained for Te, Ru, Sr and

lanthanides (used as analogues for actinides). One of the preliminary results is that the dose coefficient for ingested strontium isotopes may be higher by a factor of 3 if compared to the currently recommended ICRP values.

During the period 1985-89, a EURADOS working group on the assessment of internal doses was created. The general objective was to prepare guidance on the interpretation of monitoring data relating to internal exposure of radiation workers and the implementation of ICRP recommendations within Europe. The group has made rapid progress towards providing comprehensive European data bases for internal dosimetry, and is investigating whether European registries of internal dose assessment models, autopsy data and other biological data are feasible. This group works in close cooperation with the corresponding EULEP group on the human lung, on subjects such as deposition and clearance of inhaled particles.

I.5. POST-CHERNOBYL ACTION

Action IV. MONITORING AND SURVEILLANCE IN ACCIDENT SITUATIONS

The preparedness for monitoring and surveillance after an accidental release of radionuclides to the environment requires the appropriate techniques and the organisation of measurements and evaluations at various points in time and on different levels:

- detection of accident;
- early measurements to determine the need for countermeasures;
- continuing surveillance of radionuclides in environment, in foods and in people;
- radioecological research studies in order to improve predictive models.

The work in this action documented that there are, in general, suitable techniques available to make rapid and reliable measurements of gamma-ray dose rates and surface contamination. However, the quality of the results depends distinctly on the expertise and competence of the persons carrying out the measurements. There is clear evidence for the necessity to standardise and harmonise measurement procedures. Moreover, more consideration must be given to potential accidents that may not release gamma-ray emitting radionuclides and to accidents involving nuclear weapons and satellites powered by plutonium sources.

The metrological basis for a national network for on-line early warning with a high sensitivity to accidental discharges and good discrimination against variation in natural radiation levels was successfully developed. Using long-term experience of local conditions and climate variations in a model to analyze dose rate measurements, an algorithm was developed which allows for the discrimination of accidents if the dose rate level increases by 5% in dry weather and 20% during rainfall.

Several instruments to measure gamma dose rates were compared for their suitability for measuring background dose levels and for use in emergency situations.

All instruments tested are capable of giving a reliable indication of significant changes in environmental dose rates. The temperature dependence of instruments using scintillation detectors was relatively high in contrast to Geiger Müller counters and high pressure ionisation chambers.

Measurements of surface contamination with beta-emitting radionuclides using commercial instruments revealed differences of results over one order of magnitude. In-situ gamma-ray spectrometry using operational germanium detectors are important tools for the measurement of surface contaminations. However, the data provided by simple processing equipment of field instruments need careful analysis by trained operators.

Rapid methods of radionuclide analysis in environmental materials were systematically investigated and new rapid methods for the determination of Sr-90 was tested and validated. One relevant recommendation resulting from this investigation is that the required detection limits should be specified in advance so that the sample size can be decided. The time required for sample preparation depends on sample size.

The collaborative group recommended that additional methods and techniques are included into monitoring and surveillance procedures. In particular, sampling from aircraft and aerial surveillance techniques may be suitable. There is a need for simple screening of contaminated goods, animals and people. Guidance has to provided in advance of any future potential accident on sampling, measurement and reporting procedures so as to ensure the quality and comparability of the data.

I.6. SUPPORT TO SCIENTIFIC COLLABORATIVE GROUPS: European Radiation Dosimetry Group (EURADOS)

The collaborative European Radiation dosimetry Group (EURADOS) was founded in 1981 under the auspices of the Programme. The Programme supported EURADOS financially ever since its foundation.

Its original global objectives were:

- The stimulation of collaborative research and technical developments concerning the measurement and evaluation of exposures to and risks of ionising radiation.

- The harmonisation of methods of assessing radiation exposures by means of intercomparisons, workshops and active collaboration between laboratories in Europe.

- The collection and evaluation of physical data relevant to dosimetry and the assessment of occupational, accidental and environmental exposures of the population in the European Community.

At present, some 180 scientists from 65 laboratories in Western Europe participate in the work of EURADOS. Participation is not restricted to Member States, and from the onset scientists from countries such as Sweden and Switzerland were active EURADOS members. More recently, scientists and laboratories from countries in Eastern Europe have started to join the group. This collaboration and interaction with institutes from non-Member States has proven to be very effective and useful.

The work of EURADOS is predominantly performed by working groups consisting of 10-20 scientists including corresponding members from USA and Canada. The objectives and terms of reference are laid down by the EURADOS Council after consultation with the responsible Programme Manager. Some details of the work carried out since 1985 are given above in the respective subject area. In summary, most of the work in the EURADOS Working Groups has to be considered effective and successful. The intensive contacts and cooperation between laboratories developed within EURADOS activities very much facilitated the introduction of the multinational multi-partner contracts in 1990.

Since 1990, EURADOS has modified its mode of operation and objectives in order to avoid duplication of the coordination efforts within multi-partner contracts. EURADOS has started to get actively involved in education and training activities such as the organisation of training courses and it provides services required for radiation protection research and regulation. An example for the latter is the development and maintenance of methods for numerical dosimetry which are needed for the implementation of new quantities and concepts as those recommended by ICRP or ICRU. EURADOS continues to organise scientific workshops on specific topics which has contributed towards a world wide recognition of EURADOS competence in radiation protection research.

I.C. CONCLUSIONS AND PERSPECTIVES

Dosimetry provides a base for the majority of the other research activities in radiation protection and it contributes towards the development of techniques and procedures in operational radiation protection.

The leading role the European Communities play in the development of dosimetric concepts, quantities and instrumentation is based on the continuity of the programme and the high level of quality of fundamental and applied research. For the same reason, implementation of new concepts and quantities into regulation is efficient and uniformity is achieved in the dosimetric approach in Member States.

The cooperation with the US DOE and AECL Canada has resulted in intensive information exchange and collaboration contributing towards increased efficiency. The collaboration within the countries of the EC is excellent due to the continuity of the work, the coordinating and collaborative efforts of EURADOS and its working groups and, more recently, through the introduction of international multi-partner contract research in basic radiation physics continues to be an important tool for teaching and training.

The following important scientific achievements of the biological effects part of this sector deserve special mention:

- Instrumentation for area monitoring and work place spectrometry: the application of up-to-date digital and analog electronics as well as new material has resulted in remarkably good results.

- Skin dosimetry: the close collaboration of physicists and biologists, with the help of EURADOS and EULEP, was the basis for a rapid solution of conceptual and practical problems in an area, the relevance of which had been neglected for a long time.

- Internal dosimetry: the efforts have been increased considerably and the progress in the development of metabolic-dosimetric models is impressive.

- Numerical dosimetry: unique expertise has been accumulated in several institutes within the EC which is of fundamental importance for conceptual and practical developments.

In the light of the achievements, it is believed that the forthcoming programme should emphasise the following subject areas:

1. External Irradiation

There is an increasing need for exposure specific monitoring of occupationally exposed individuals (examples: civil aviation, high energy and medical accelerators, space mission, fusion, variable mixed radiation fields in nuclear industries, radon) in order to be able to comply with future exposure limits. This requires research in the development and improvement of individual dosemeters as well as complementary methods for work place analysis. Required work includes physical research for high energy radiation for which the data base is relatively poor.

The harmonised implementation of exposure limiting and monitoring concepts require tools for performing the necessary calculations, calibration and development of standards. Calculational and experimental methods are necessary to continue to develop and use anthropomorphic and calibration phantoms and to provide data for radiation protection practice and risk assessment.

2. Incorporated Nuclides

The research needs and priorities for the dosimetry and monitoring of incorporated nuclides are mainly given by the still considerable lack in the knowledge of biokinetics and fundamental processes.

The implementation of limits for internal exposure through derived limits for intake of radionuclides requires improvements in the knowledge of nuclide, speciation, age and sex specific biokinetic data. The study of doses to the developing foetus and

reproductive organs requires specific attention.

The methods of monitoring internal exposure and contamination have to be improved, in particular for nuclides emitting short-ranged particles. For accident situations, rapid methods of dose assessments have to be developed (external measurements, bioassays).

Radiation protection against radon progeny should finally be based on a dosimetry approach which is part of the general dosimetry of ionizing radiation. Corresponding research aimed at improved understanding of the relationship between exposure, dose and risk and at developing suitable instrumentation is required.

The interface between research in radioecology and internal dosimetry must be clearly defined and used.

3. Dose Reconstruction and Retrospective Dosimetry

The methods for dose reconstruction and retrospective dosimetry for accidental and occupational exposure have to be systematically investigated. The quality of results of health effect studies using epidemiological methods depends critically on the uncertainty of the assessment of doses to individuals and organs.

Physical methods to retrospectively measure and calculate exposure to various types of radiation should be analyzed with regard to their potential in dose reconstructions, in particular at low dose levels.

Biological methods for dose assessments should be used to complement the physical methods.

4. Microdosimetry

Research in microdosimetry is a tool for low dose effect studies, which is aimed at providing constraints for the extrapolation of results obtained for high doses to the low doses relevant in radiation protection and at understanding radiation quality aspects.

The goal of understanding mechanisms is a long-term objective which requires in the medium term improvement of model calculations using large computers and integrating step by step physical, chemical, molecular, cellular knowledge and data. There should be a two way interaction between the microdosimetric calculations and the chemical and biological investigations.

Scientific achievements in microdosimetry and progress in the availability of methods should be examined with regard to their suitability to be applicable directly for radiation protection problems. Examples are microdosimetric detectors used for monitoring and microdosimetric empirical models for the systematic analysis of radiobiological data.

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II.C. CONCLUSIONS AND PERSPECTIVES

II. RADIOECOLOGY

II.A. INTRODUCTION

Compared to the previous programmes, research activities in the period 1987-1991 focus more on critical problems of radioecology where special attention was paid to the long-term behaviour of radionuclides, in particular actinides, technetium, caesium, strontium and the influence of the physico-chemical status of the radionuclides on transfer. The Chernobyl accident drew attention to some areas which had not been studied very much, in particular the transfer of radionuclides in animals, the behaviour of accidentally released radionuclides in semi-natural ecosystems and the practical implementation of countermeasures.

In the period 1985-1989 investigations concentrated on:

1. Terrestrial environment

    1a. The behaviour of actinides and other long-lived radionuclides;
    1b. The behaviour of technetium in terrestrial environments;
    1c. The behaviour of tritium;
    1d. The effect of countermeasures.

2. Aquatic environment

    2a. Radioecology of continental rivers and modelling of river systems;
    2b. The behaviour of long-lived radionuclides in the marine and estuarine waters.

In the second period (90-91) the emphasis is much more directed towards an integrated research where the dynamic interaction between the ecosphere and the radiocontamination is taken into consideration and less on mere measurements of contamination levels. This is made compelling by the awareness that control of the radioactivity in the environments implies to control the environment as a whole. At the same time, however, this poses problems, because some scientists have been trained in nuclear physics or in radio-analytical chemistry and not in the field of ecology. They have thus to be trained in this discipline and become accustomed to this integrated approach.

The topics in the area of radioecology in 1990-1991 were as follows:

1. Terrestrial environment

    1a. Investigations and Modelling of the Dynamics of Environmental HT/HTO/OBT Levels Resulting from Tritium Releases;
    1b. The Bio-Availability of Long-Lived Radionuclides in Relation to Their Physico-Chemical Form in Soils Systems;
    1c. Transfer of Radionuclides in Animal Production Systems;
    1d. Cycling of Caesium and Strontium in Forest Ecosystems;

1e. Deposition of Radionuclides on Tree Canopies and Their Subsequent Fate;
1f. Radiation Doses and Pathways to Man from Semi-Natural Ecosystems;
1g. Pathways of Radionuclides Emitted by Non Nuclear Industries;
1h. Transfer of Accidentally Released Radionuclides in Agricultural Systems;
1i. Studies of Methods for the Rehabilitation of Soils and Surfaces After a Nuclear Accident.

2. Aquatic environment

2a. Towards a Functional Model of Radionuclide Transport in Freshwater;
2b. Mechanisms Governing the Behaviour and Transport of Transuranics and Other Radionuclides in Marine Ecosystems.

B. SCIENTIFIC ACHIEVEMENTS

II.1. TERRESTRIAL ENVIRONMENT

II.1.1 The behaviour of actinides and other long-lived radionuclides

The transfer of radionuclides has been shown to greatly influenced by the soil type and soil treatments. Investigations of the role of the liquid phase gave an insight into the mechanisms of transfer from soil to plants. In addition to a comprehensive chemical analysis of soil solutions, a detailed study of the chemical form (speciation) of the radionuclides is needed. Laboratory experiments, under conditions of radionuclide equilibrium, have provided initial information for practical assessments of the value of countermeasures on soil contamination. The role of the solid interphase has been quite successfully studied and a clear picture is developing which allows a description of the role of specific absorption sites inside the soil solids but which also provides for a role of the organic matter in specific soils. The fine balances are now being quantified more rigorously, which will allow more reliable prescriptions for the applications of fertilizers as agricultural countermeasures.

II.1.2 The behaviour of technetium in terrestrial environments

Technetium-99 is a fission product in reactors and it was given much attention because it represents a significant component of discharges to the environment from enrichment and fuel processing and is readily transferred in the environment. Technetium is subject to easy chemical speciation changes due to its redox characteristics. Redox processes therefore play an dominant role in its long-term behaviour in soils and animals. The research has led to the general conclusion that the simpler the chemical form of Tc (pertechnetate) the more readily it is transferred in the environment. Since, however, this element is constantly changing its oxidation status due to its multitude of interactions with the chemical and biological status of the environment, a set of retardation compartments and factors is built up. Eventually however all technetium will become pertechnetate and will

potentially be transferred to the end points of a food chain. This research has been concluded because the major questions have been answered. The basic knowledge acquired should now be used in practical applications. These studies moreover had been able to derive the essential parameters needed to describe the behaviour of this element, and some of the relevant methods are now applied in other areas.

II.1.3 The bio-availability of long-lived radionuclides in relation to their physico-chemical form in soil systems

The aim of this research is to study the mechanisms of uptake of radionuclides from the soil/soil solution media into plants. Different approaches are used in order to differentiate the plant specific uptake from effects due to soil characteristics. Laboratory experiments and lysimeter experiments are used together with field experiments. A number of important findings about e.g. sorption/desorption, uptake of Cs and Sr by plants, and interactions between competing ions, organic matter content and mineral structure of the soil came out of this research. Sorption and desorption phenomena of caesium seem to be controlled by different ionic competition mechanisms.

Other data suggest that the effects of changes in the mineral nutrition of a crop on the transfer of e.g. radiocaesium were less important than the physical characteristics of the soil on availability. It would appear that Ca by its very presence, may play a more dominant role in controlling the transfer mechanisms, even of Cs, than has been expected. However very clearly the role of organic matter as compared to clay minerals is far from being satisfactorily resolved.

II.1.4 Pathways to man from semi-natural ecosystems

Semi-natural environments, for example meadows, moorland used partially for human food production, came into prominence when, after the widespread contamination caused by the Chernobyl accident, high levels of transfer of radioactivity into the food chain were found. The relatively rapid transfer of caesium can be attributed to the high organic content of the soils. The role of a number of different physico-chemical parameters controlling the behaviour of radionuclides in these ecosystems are being studied. The overall aim is to work out appropriate radioecological models. The large number of parameters involved and anticipated large variability makes this a difficult task, which perhaps implies a limitation of scope. The study of these particular ecosystems suffers from the fact that for many years radioecology concentrated on agricultural environments, which ecologically speaking are much more simple systems. Methodology has had to be adapted and new definitions of transfer parameters introduced. The diversity of the subject is becoming apparent. Much emphasis has been placed on inter-comparison exercises. In the different semi-natural ecosystems investigated, it has been shown that up to 95% of the deposited Cs-137 is still retained in the soil compartment. Plant uptake within the systems is high (with exception for the greek soils, which have a higher clay content and neutral pH) and there is no evidence of a progressive fixation of Cs-137. The animal compartment represents, in most cases, less than one (1)% of the

Cs-137 within the ecosystem. There seems to be a relation between microbial respiration rates and radiocaesium migration. Sr is immobilised more effectively than Cs in organic soil.

Calculations of total deposition usually involve the sampling of both soil and bulk vegetation. One of the variables which may give rise to a divergence of results is the sampling technique used. Soils typical of semi-natural ecosystems often have a high moisture content and a heterogeneous vegetation cover. Both of these features imply that sampling methodologies used routinely for lowland agricultural soils may be inappropriate for semi-natural ecosystems.

II.1.5 Deposition of radionuclides on tree canopies and their subsequent fate

II.1.5.a. Deposition

The objectives are to investigate the physical processes resulting in aerosol capture and subsequent losses and recycling in forest ecosystems. The wind tunnel work simulating aerosol capture by forest canopies shows a very high degree of sophistication and interesting results on aerosol dry deposition velocities and interception fractions are being obtained. Considerably higher deposition rates are observed in canopies of deciduous trees compared to coniferous trees and to on grass canopies.

Relatively small and particle size independent deposition velocities were observed for particles below around 1 μm. Above this critical size, the deposition velocity was shown to increase abruptly with the size of particles. It was also shown that lower wind speed brings lower deposition in leaf canopies as well as on single twigs exposed to stable monodisperse aerosols.

Field experiments showed no differences between air concentrations of several elemental and ionic species at two different heights within a canopy, thus arguing for a low deposition of the concerned aerosols.

Laboratory experiments on a "model" canopy placed in a wind-tunnel gave on the contrary high deposition velocities. The reason for the discrepancy between field and laboratory experiments are not quite clear.

On the whole the total interception fractions are usually very low in forests.
Mosses could used as bio-indicators for wet deposition levels under certain conditions.

II.1.5.b. Cycling of Radionuclides in Forest Ecosystems

The overall aim is to reveal the dominant parameters which govern radionuclide cycling in forest ecosystem and to work out an appropriate radioecological model describing this process. Forest soils are generally characterized by widely undisturbed profiles, going from organic horizons (strata), through inter-mixed

organic-mineral horizons to mineral horizons with all having different physico-chemical and biological characteristics. In these soils Cs is mainly retained in the layers with a high organic content, whereas Sr is more homogeneously distributed. This is similar to their behaviour in non-forested seminatural ecosystems. In forest ecosystems a huge variety of plant species occur, which can however be classified into a set of 4 groups on the basis of radionuclide data and their ecological behaviour. This may permit a simplification of the ecosystem for modelling purposes. Accumulation of radiocaesium in fungi occurs predominantly in symbiotic species and less in saprophytes and parasitic fungi. In forest soils the symbiosis between fungi and plant roots seems to be very intensive. Currently, however, not enough information is available to quantify the influence of symbiotic transfer mechanisms on the amount of ^{137}Cs activity in autotrophic plants.

As a whole it can be said that the efforts to quantify the relation between the level of soil contamination and the level of plant contamination has not yet been very successful, the mechanisms being much more complicated than in regularly cultivated (disturbed) agricultural soils.

In semi-natural and forested zones the levels of contamination in herbivores (e.g. moose) is very difficult to predict, especially when traditional compartmentalised approaches to radionuclide behaviour are used, giving incomplete information of mechanisms, processes and functional units. Instead transport of radionuclides in food chains ought to be studied on the basis of population ecology taking into account the variable behaviour of individuals in these populations. This approach might give a more detailed knowledge of mechanisms governing uptake in the population and give an explanation to the dramatic changes in the level of contamination of the animals in different years, seasons and regions. The two important factors which seem to govern the transfer of matter in ecosystems are the presence of herbivores and litter fall with its associated decomposition of organic matter in soil. The relative importance of the different processes are ,however, controversial.

II.1.6 Transfer of radionuclides in animal production systems

The objectives of the experimental work are to formulate models able to encompass the essential factors determining the role of both farm and free ranging animals in the transfer of radioactivity to man.The studies performed in the 2 year research programme have attempted to identify and quantify some of the most important factors influencing the levels of radiocaesium in animal food products mainly derived from sheep and cattle.

Two points are of main interest in the project: the absorption in the ruminant gut and the influence of soil adhesion to grass and fodder.

The studies on gut absorption have attempted to identify the underlying mechanisms governing radionuclide transfer, rather than using only empirical measurements such as concentration ratios, and have successfully described the transfer mechanisms from feed to blood plasma. This intrinsic gut absorption coefficient

seems to be rather constant independently of the animal species investigated.
As far as transfer to muscle and milk is concerned, the transfer to different muscle types depends on the fibre type, the transfer to milk depends proportionally on the milk production rate. Although soil adhesion to the vegetation may play a role to transfer radiocaesium to the gut of an animal, its relevance depends on the degree with which the radionuclide can be desorbed from the soil and thence become involved in the usual gut absorption.

Thus, the true gut absorption coefficient A_t, which is a metabolic parameter, seems to be only slightly influenced by the fodder composition, whereas the overall transfer factor F^f is dependent on the chemical composition of the fodder. Countermeasures have to take the fine balance between this two parameters into account. The transfer parameters under investigation were assembled in a number of modelling exercises, where it is to be realised that the boundary conditions of the equations leave room for volume changes such as growth or quantity of milk production during lactation instead of simply taking concentrations as independent parameters. The models have also again underlined how important it is to consider the impact of grazing habits and grazing pressure on the contamination levels of the free ranging animals.

II.1.7 Investigations and modelling of the dynamics of environmental HT/HTO/OBT levels resulting from tritium releases

In order to assess the risks of tritium to man the fate of tritium in soils, plants and animals is being investigated. Deposition on soil and uptake into plants of tritiated hydrogen gas (HT) and tritiated water (HTO) depend on several critical factors, such as air concentration, wind speed, time of day, rainfall, dew formation, accessibility of the soil surface, diffusion into the soil and, for HT, microbial conversion. The exposure of a contaminated soil to an atmosphere with lower specific activity yields an increased release rate of HTO compared to H_2O, which means that the HTO re-emission rate is increased compared to the H_2O evaporation This example shows that the HTO re-emission rate cannot be derived straightforwardly from H_2O evaporation rate. This result however does not yet permit the estimation of the inhalation dose that might arise from a contaminated soil in open air conditions because the total process is not completely understood.

Animals fed Organic Bound Tritium (OBT) adsorb more tritium in the organs than those fed tritiated water (HTO). Some OBT is retained for very long periods of time, especially when it is resorbed during lactation or pregnancy and particularly in tissues such as brains and connective tissues. Nevertheless, it is expected that these tissues would not be at risk because much of the tritium is present in extra-cellular sites and the beta radiation cannot reach the nuclei of the cells.

II.1.8 RESSAC: Rehabilitation of Soil and Surfaces following an Accident

The aims of the RESSAC projects are to reduce to a minimum the short term consequences of an accident, to predict the fate of the contamination on medium and long term and to obtain data allowing to set up intervention procedures in order

restore the environment to a "normal" situation.

Studies on the transfer of radionuclides to plant, animals and other edible products (vegetable, meat, milk...) show that the knowledge of the physico-chemical characteristics of the contamination is essential and that the spraying of a radioactive solution on soil or on plants is not necessarily representative of an accident. The radioactive aerosol generator developed is able to produce depositions identical to those anticipated in the 5 km zone in case of a PWR accident.
A decontamination-vegetal network made of shallow-rooting grass (ryegrass) which readily absorbs radioactivity and afterwards skimmed, has been developed at Cadarache. The use of organic polymer for land reclamation was tested, about 99% of the radioactivity can be removed; the mechanical adhesion between polyacrylamides and soils particles carrying the radioisotopes is the key process. Aerobic biodegradation resulted in the best volume and mass reduction of organic waste and also in the best desorption of radioactivity.

Since 1990 the RESSAC project was extended towards an EURESSAC dimension with the inclusion of Belgian, Italian, Danish laboratories. The aim of their research was to deal essentially with the soil-plant-animal transfer after a contamination with radioactive materials contained in artificially produced aerosols. Finally the global experiments (lysimeters) also involved four other European countries Belgium, Germany, United Kingdom and Spain.

II.1.9. TARRAS (Transfer of Accidentally Released Radioactivity in Agricultural Systems)

The overall objectives of the TARRAS study were on the one hand to use a simulated PWR source term to follow the behaviour of Sr, Ru and Ag isotopes in a soil/vegetable system, and also to study the extent of radionuclide transfer modified by well established food processing techniques and finally to determine relevant characteristics for dose calculation in the Southern European countries. Valuable results have been obtained on soil migration,leaf retention and soil speciation of radionuclides. In the case of food processing the effects of freezing, canning, drying, milling have been studied. Some complementary studies have been performed for juices and wine. In most cases the food processing significantly decreases the content of radionuclides in agricultural products(from 20 to 50%). The data obtained when comparing Mediterranean and other EC countries diet and production show that the differences are much less significative for diets than for food production.

II.2 AQUATIC ENVIRONMENT

II.2.1 Radioecology of continental rivers and modelling of river systems

The heterogeneity and complexity of fresh water ecosystems including different catchment and rivers or lakes presents an extra difficulty to get a clear and general picture of the radioecological contribution of such systems. The main objectives of this project on freshwater radioecology is to find out were the present generation of models break down and to improve fundamental knowledge in these areas.

A new methodology has been devised to study Cs sorption and desorption behaviour. It could be shown that desorption efficiency decreases with increasing contact time between the solid and the radiocaesium and that the desorption behaviour is not related to the initial sorption characteristics. The presence of higher Ca and Mg concentrations during adsorption decrease the desorption recovery efficiency.
In aquatic plants an obvious Cs/K interaction was observed controlled however by the presence of Ca having a direct influence on the ion uptake mechanism. The concentration of radioactivity in the plants is moreover regulated by the growth rate itself, and is thus controlled by light, temperature and nutrient concentrations.
Field measurement have shown that peat bogs in a lake catchment will continue to supply radiocaesium to the lake at a rate of about 3% of the initial catchment inventory per annum. The work suggests that lakes and reservoirs containing peat bogs will be more susceptible to radiocaesium remobilisation than formerly expected.
The studies in this project have demonstrated that many of the processes involved in the transport of radionuclides through aquatic systems are controlled by identifiable principles which can be introduced in mechanistic models. A model was elaborated consisting of four levels: a hydro-dynamic sub-model that represents and computes, for any time and any location, the flows, water heights, river cross-section and bottom pressure; a sediment sub-model that calculates concentrations of solids suspended in the water column and deposited sediments; a radionuclide sub-model assessing transport and distribution in water, sediments and suspended matter; a radioecological sub-model describing the food chain transfer and computing the amounts of radionuclides incorporated into the various biological compartments as well as the fluxes between those compartments.

II.2.2 The behaviour of long-lived radionuclides in the marine and estuarine waters

The objectives of these projects are to improve the understanding of the behaviour of transuranics in the marine and estuarine environments by studying specially the influence of the physical and chemical speciation in a range of conditions such as salinity, redox potential, organic load and others. Probably not all processes are well enough known, especially in their role as a sink.

Inventories of radionuclides in large areas of the European seas and oceans, and of their movement along with the current of the water masses have been compiled, revealing the displacement of radioactivity from their major release points at the reprocessing plants in the Channel and the Irish Sea up to the Arctic and Baltic Seas. Actinides were found to be removed from sea water by interaction with sediments. The particles, however, sediment slowly and constant interaction with the surrounding sea water occurs. The radionuclides penetrate the deep sediment layers extremely slowly and by pore water diffusion only. Formation of sea spray can lead to a contamination of a limited inland zone.

The overall objective of the above project was to refine the understanding of the behaviour of plutonium, americium and other long-lived radionuclides such as ^{90}Sr and ^{137}Cs in the marine environment. The study embraced a number of distinct

marine zones including the Irish Sea, the Normandy-Britany Gulf, the Seine Estuary, the Almanzora Canyon (Palomares) and adjacent Shelf, the Gulf of Taranto-Ionian Sea and the Balearic Sea area. Although these domains differ widely in their physical oceanography (contrast the mega-tidal Normandy-Britany zone with the weakly tidal Mediterranean), many of the fundamental processes governing the behaviour of transuranics and other long-lived nuclides are common to them all and, accordingly, were the main focus of the work undertaken by the participants.

II.2.3 Pathways of radionuclides emitted by non-nuclear industries: behaviour of Po-210 and Pb-210 in European estuaries. Application of bioindicators

The aims of this study are to obtain insight into the impact of the phosphorous industries on the activity levels of Po-210 and Pb-210 in estuaries and coastal waters of Western-Europe, to find good bioindicators, to assess the dose to the population stemming from the marine environment and to develop a model predicting the levels of radionuclides in the different compartments of the estuaries.

Levels of radioactivity measured in suspended matter seem a better indicator for industrial enhancement than the levels dissolved in water. The largest enhancements were observed in bottom sediment near the outfalls. In the Seine estuary it was found that Fucus vesiculosus is not suited as a Po-210 bioindicator, whereas Mytilus edulis is. The physico-chemical properties of the river, the tidal current velocity, the estuary volume and of course the emission of Po-210 are the most important factors determining the estuary emission to the sea.

II.3. POST-CHERNOBYL ACTIONS

Action II. EVALUATION OF DATA ON THE TRANSFER OF RADIONUCLIDES IN THE FOOD CHAIN

Four major research areas were considered: chemical speciation, soil-plant transfer, plant-animal transfer and transfer in aquatic systems.

Sixteen radionuclides were detected in the aerosols from the accident. The solubility of the radioecologically important radionuclides appeared to be similar to that of the relevant stable elements, thus depending on their chemical properties.

In agricultural ecosystems soil to plant transfer ratios for radiocaesium originating from the Chernobyl accident were about two times lower than that of radiocaesium from other contamination sources. Discrepancies in the data set were apparently associated with three main factors; (i) changes in availability with time, (ii) large data sets from areas with high organic matter content soil and (iii) foliar absorption and translocation.

In semi-natural environments soil-plant transfer factors are consistently higher for radiocaesium than initially expected. In many of the contaminated soils, particularly podzols, radiocaesium from Chernobyl has been retained in the top few cms of the

soil profile and is hence still within the rooting zone of many plant species.

Valuable information has been obtained on the transfer of radiocaesium into animal products from both semi-natural areas and agricultural areas. From these studies a number of general points can be highlighted: transfer factors for milk and meat vary with animal species, being higher in general in goats and sheep compared to cows; higher transfer occurs in younger animals, but transfer is lower in foetuses; transfer factors are dependent on the physico-chemical form of radionuclides.

The Chernobyl accident provided a, scientifically, very useful test of the understanding of the transfer of radionuclides through aquatic environments. Experience from weapon fallout suggested that the majority of deposited radiocaesium(in particular) was immobilised immediately on making contact with the ground or, when it fell directly into water, immediately on making contact with the sediments. Measurements, however, made within a few months after the Chernobyl deposition have shown many samples of Cs-134 being found at depths in sediments deeper than those expected from the accumulation rates from clear Cs-137 profiles from weapons fallout. Since transport to these depths by mixing processes such as bio-turbation by sediment living animals would also have destroyed the fallout profiles, the data suggest that Chernobyl material was more mobile than material from weapons fallout.

The transport of material from the catchment was suspected to influence the concentration of radioactivity in rivers and lakes and a survey of several lakes along a line of constant deposition showed that lakes within a few kilometres of each other could have very different radiocaesium concentrations even though the original deposition was the same. Data suggested that this may be the result of deposition onto organic peat catchments where Cs was only weakly bound and that chemical processes could bring it back into solution and so into lakes and rivers. The presence of peat seems nevertheless not sufficient on its own to explain the enhanced run-off found in certain areas.

Because quasi-steady-state conditions were introduced during the deposition of weapons testing fallout it was possible to use simple factors to estimate the concentration of Cs in fish, given the concentration in another phase, usually water. However, the dynamic nature of the Chernobyl event did not allow a steady state to develop so that concentrations in the fish predicted by this method bore no resemblance to what was measured. When however the concentration of radionuclides in the sediments was used as a base of the calculation a better prediction, however, could be made.

Action VI. IMPROVEMENT OF PRACTICAL COUNTERMEASURES AGAINST NUCLEAR CONTAMINATION IN THE AGRICULTURAL ENVIRONMENT

It is quite clear that, with some exceptions, reclamation of rural areas after accidents, had not been given much attention in the pre-Chernobyl era. Nevertheless contamination of some rural areas in or near the site of a nuclear

accident, a nuclear test or a high radioactivity release have posed problems of reclamation and of research on this subject.

With that purpose a number of scenarios, which had been used in the past, have been compared, aiming at collecting information on:

- Deposition of contamination on vegetation and soils (direct contamination);
- Behaviour of contaminants in the soil and transfer into the plants (indirect contamination);
- Reduction of the contamination levels in the rural environment by:
  The decontamination scenarios of important accidental situation were assessed regarding accident conditions, methodology of decontamination, and the efficiency, feasibility and practicability of the scenarios.

Action VII. IMPROVEMENT OF PRACTICAL COUNTERMEASURES: THE URBAN ENVIRONMENT

In the event of a severe nuclear accident releasing, predominantly, the more volatile radioelements, in particular radiocaesium, strategic plans for managing and eventually decontaminating and reclaiming a contaminated urban complex may be called for.

Two different approaches were adopted in this study. While recognising the importance and practicability of the empirical approach as a mean of estimating what can be achieved in dose reduction, considerable efforts were also devoted to understanding the interception and retention of caesium on urban surfaces, which in turn are indicators of the limitations of some of the empirical decontamination methods.

It was also investigated how surfaces might be treated to reduce their capacity to absorb and retained fallout radiocaesium. Finally a draft strategy for tackling a contaminated urban environment was developed, which can serve as a basis for future studies.

II.4. SUPPORT TO SCIENTIFIC COLLABORATIVE GROUPS: International Union of Radioecologists (IUR)

The International Union of Radioecologists (IUR) has several objectives, ie, to stimulate the cooperation and exchange of information between radioecologists, in particular those from countries outside the European Community, in order to stimulate interactions that would increase the understanding of problems of radioecology; training of young scientists; preparation and publication of relevant handbooks for radioecological use.

The efforts of the International Union of Radioecology in the past period are fully appreciated especially the role it has played in prospecting the relevant scientific situation in the former Soviet Union. This has been extremely useful when our

Action had to establish its own contacts in relation to the planning and organisation of our research with CIS authorities and Institutions. This led to a very successful Seminar in Luxembourg, jointly organised between CEC and the IUR, on a comparison of three major accidents i.e. Chernobyl, Khysthym and TMI.

The IUR has done a good job in the training of young radioecologists and a continuation in the forthcoming years is anticipated. To support this training activities a.o. the publication of a "Handbook of Radioecology" is being foreseen.

In order not to loose momentum, the structure has been adapted to the new situation of the coordination of the current Research Action. To avoid overlapping work in the future with the CEC multi-partner projects well defined tasks (Task Forces) have been formulated.

II.C. CONCLUSIONS AND PERSPECTIVES

In this period an evolution has taken place in the way radioecological problems have been assessed due to developments in the scientific society as a whole, due to changes in insights and also due to the accident at Chernobyl. Radioecologists have been confronted with the fact that their discipline is much more than the measurement of contamination levels for the purpose of prediction, and that contamination can precipitate not only on the rather well understood agricultural fields but also on much less explored and understood semi-natural environments. In addition they realise also that the results of their research should lead to a more efficient control of the contaminated zone and to a consideration of impact of restoration practices on the ecological equilibrium of affected areas. The complexity of the ecological and human interactions with and within these ecosystems have and have forced the scientists to reconsider their definitions and scientific approaches to comprehend and understand these systems.

Certain approaches have assumed greater prominence than in the past; these are the influence of chemical, physico-chemical and biological conversion on the transfer of radionuclides in all environments. There has consequently been a development towards a much more integrated approach in the whole field of radioecology.

Some key points emerge from the ongoing research and the final reports:

- it is at last becoming clear and almost common practise in all the radioecological projects to consider the physico-chemical nature of radioactivity interacting with the environment, and radioecological modelling is beginning to take this fact for granted.

- studies of radionuclide behaviour in soils have essentially been limited to rich agricultural land which is rich in minerals and organic soils have not been given much attention even not in general soil science. Consequently a satisfactory description of the role of litter deposition and of organic matter in the retention and availability mechanisms of radionuclides is not yet available!

- the scientists involved in research regarding the radioecology of the terrestrial environment and the aquatic environment are beginning to recognise that mere measurements of contamination levels in such ecosystems does not lead to straightforward conclusions and that not only physical and biological half-lifes have to be taken into consideration but also the whole complexity of the ecosystems.

- some of the scientists involved in making mathematical syntheses of experimental exercises are now beginning to develop models which take into account that the fluxes of radioactivity through environmental compartments are the results of both changes in quantities and volumes and can therefore not be described by concentration changes in the different compartments only.

The following important scientific achievements of the radioecology part of the programme deserve special mention:

Terrestrial environment

- Investigations regarding the soil-liquid phase give an insight into the mechanisms of transfer from soil to plants; successful work has been achieved on the role of the soil solid phase;
- Investigations were made to work out appropriate radioecological models for the cycling and persistence of radionuclides in semi-natural environments like meadows and forests; an adaptation of the methodology and quantities was necessary;
- Construction of models fit to encompass the essential factors determining the role both of farm animals and free grazing ones in the transfer of radioactivity to man;
- Remedial actions such as the use of selected fertilising practices, feeding additives to animals etc, with respect to contamination in the near, intermediate and far field of an accident site were considered after the Chernobyl accident in all relevant projects. Achievements of the RESSAC and TARRAS projects are:
    - Decontamination of soil surfaces by a vegetal network (ryegrass) leading to a removal of the introduced radioactivity of about 75% for both Cs and Sr, by skimming off the top layer of soil trapped by the shallow rooting of the grass;
    - Removal of fresh and dry biomass waste products by aerobic and anaerobic degradation.

Aquatic environment

- Determination of transfer through trophic food chains, and the characterisation of the physico-chemical behaviour in fresh-water environments were carried out in order to model the transfer of radioactivity in river systems;
- Improvement in the understanding of the behaviour of transuranics in the

marine and estuarine environments and especially the role of physical and chemical speciation in a range of environmental conditions.

The following objectives have to be borne in mind when defining the research directions:

The studies must allow a prediction of the levels of radioactive contamination and lead to a calculation of external and internal population radiation doses. These doses can be incurred by members of a population by the use they make of a contaminated environment through its food and industrial products and of their general interaction with the same environments.

The studies must allow control, management and restoration of the contaminated environment with the least harm both to the ecosystems and to man. The studies must serve training purposes, and give the opportunity to make the scientific information available to related scientific disciplines.

Radioecology aims therefore at investigations of the external (e.g. climate and climate changes) and intrinsic (bio-physico-chemical factors) factors determining the behaviour and ecological half-life of radionuclides in the ecosphere. Intrinsically the research can therefore only be carried out by multidisciplinary teams. The approach is split into two parts, encompassing fundamental research areas studying the basic processes with the aim to improve the predictive capabilities of ecological models and mission oriented areas to answer explicit questions in e.g. emergency management.

Radioecology used to be very much restricted to measurements of contamination levels in the environment, in particular in agricultural ecosystems. It seems that for most of the commonly released radionuclides the data are known with some statistical accuracy and therefore limited information is still needed. Extensive literature and transfer factor tables are now available. The data can moreover be corroborated or rejected at any time by real time measurements.
Research should be much more directed towards an ***integral research*** where the dynamic *interaction* between the *ecosphere* and the *radio-contamination* is taken into consideration. This is made more compelling by the awareness that controlling the environment conducts to controlling radioactivity in the environment as a whole. Newer problems have been and are arising in ecosystems, that may be potentially endangered, but whose size and ecological particularities have not yet been fully comprehended This applies especially to the marine world, and in semi-natural environments where it appears necessary to introduce the concept of ecological half-life determining the eventual availability of the radioactivity in time, or with regard to the transfer of radionuclides in animal production systems and the contamination of animal products.

For environmental restoration (engineering) such as e.g. forest felling and treatment of the waste, fertiliser application, animal treatment, engineering and management of radioactivity dumped by accident in marine environments eventually affecting water-surrounded areas etc., the state of knowledge is not fully satisfactory, also with respect to the long-term effect of the countermeasure techniques. Only rather

recently has it been recognised that the traditional environmental modelling is not fully appropriate for these purposes, because it was not designed for it. It does not indeed very much take into account the interactions between the active processes in the geo- and biosphere (= ecosphere) and the behaviour of the released radionuclides on the long term. Radioecology is being focused and will have to focus even more on these interaction processes if it is to propose successful restoration practices. Trial and error in attempts to mitigate an environmental emergency situation, especially on the long-term, has not always been shown to be either cost or technically effective and which may lead to the risk of serious damage to the environment and its consumers. In this respect the use of additives of all sorts to treat land and animals has to be handled very carefully for reasons of technical efficacy, economical feasibility and retarded negative effects (changes in the nutritional quality of the food products and effects on health). The situation is far from satisfactory for the time being, notwithstanding the considerable efforts of competent scientists and the publication of specialised proceedings.

In the area of ecological engineering the impact of environmental restoration practices on the ecological stability, health and accessability of these environments has hardly ever been considered! Studies, therefore, of the consequences of the application of countermeasures on the medium and long term stability of the affected ecosystem, and studies of the value on the long term of the treated ecosystem would by all means improve the state of the art.

III. CONSEQUENCES OF RADIATION EXPOSURE TO MAN

III.A. INTRODUCTION

III.B. SCIENTIFIC ACHIEVEMENTS

III.1. STOCHASTIC EFFECTS OF RADIATION

- III.1.1. Microdosimetry and biophysical modelling
- III.1.2. Repair of DNA damage
- III.1.3. Cytogenetics and cell radiobiology
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  - III.2.1.a. Treatment of radiation accidents and underlying pathogenetic mechanisms
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- III.2.2. Radiation damage to skin and other underlying tissues
- III.2.3. Radiation effects in the lens, the thyroid and the lung

III.3. RADIATION EFFECTS ON DEVELOPING ORGANISM

- III.3.1. The cultured embryo model
- III.3.2. Brain and haemopoietic damage
- III.3.3. Carcinogenesis in the developing organism
- III.3.4. Studies on transfer of radionuclides in utero

III.4. POST-CHERNOBYL ACTIONS

III.5. SUPPORT TO SCIENTIFIC COLLABORATIVE GROUPS: European Late Effects Project group (EULEP)

III.C. CONCLUSIONS AND PERSPECTIVES

III. CONSEQUENCES OF RADIATION EXPOSURE TO MAN

III.A. INTRODUCTION

Two types of radiation effects must be distinguished: **non-stochastic effects**, typified by acute and many late radiation syndromes, are due to the death or functional impairment of many cells and, therefore, arise only above a threshold dose. Since radiation standards are set below these threshold doses, non-stochastic damage occurs only after accidental or therapeutic exposure. Effects on developing organism may be an exception because it is not yet known whether a threshold exists for damage to the developing brain.On the contrary, **stochastic effects** to a single cell can be transmitted to the progeny of this cell either in the same organism, giving rise to cancer or, to future generations, causing hereditary alterations. Such changes may arise without a threshold.

Causation of malignant tumours represents the problem of greatest concern in radiation protection of workers and the public since such stochastic effects may arise at low doses without a threshold at full severity as a consequence of genetic alterations in a single cell. The progeny of such transformed cells can then divide to form the tumour or, in the case of genetic damage in germ cells, be transmitted to the offspring. Radiation exposure from natural, medical or industrial sources occurs mainly at low doses and at low dose rates; an understanding of the mechanisms of action of radiation at the cell level and the quantitative definition of the risks of cancer from such exposure are, therefore, a central problem in radiation protection.

In the periods 1985-1989 investigations of the stochastic effects concentrated on:

1. The molecular basis for alterations in the chromosomes of the cell;
2. The mechanisms by which cells are transformed and tumour growth is promoted after irradiation;
3. The dependence on dose and exposure conditions for radiation-induced cancer in animal models pertinent to the human situation;
4. The relation between deposition of radionuclides in tissues and their action on biological target structures;
5. The frequency and types of cancer in exposed human populations.
6. The hereditary effects of radiation such as translocations and specific locus mutations.

No area of research on radiation-induced cancer, be it molecular biology, cellular investigations, animal study or epidemiology, can by itself provide a direct answer to the problem of risks of low doses of radiation delivered at low dose rates; rather, one must integrate the information obtained from these different approaches to allow extrapolation to dose levels for which a reliable detection of the carcinogenic effects is not possible any more because they occur so rarely.

In accordance with the recommendations made in the 1985-1989 evaluation, the current programme has a far bigger contribution from molecular biology and, indeed,

the developments in this area are some of the most exciting in the biological effects sector. The new multi-partner contracts initiated in 1990 have been most successful and have facilitated the improved collaboration between laboratories. In the 1990-1991 programme the research, while remaining essentially an elaboration of that developed during the 1985-1989 programme has nevertheless concentrated on:

1. The further development of microdosimetry and biophysical modelling;
2. The identification and cloning of human DNA repair genes;
3. The study of the effect of chromatin structure on DNA repair;
4. The identification of the molecular lesions giving rise to chromosomal aberrations;
5. The development of human epithelial cell lines for the study of transformation;
6. The development of refined analytical techniques for use in animal carcinogenesis;
7. The early chromosomal changes leading to leukaemia induction;
8. The induction of genetic effects in germ cells, including a consideration of genetic risk for disease with a partial genetic component.

The second type of radiation effect, non-stochastic effects may take various clinical forms with different symptoms, depending on the tissue which has been irradiated and the level of dose. These effects are the result of whole-body or local exposures that cause sufficient cell damage or cell killing to impair function in the irradiated tissue or organ. The damage is the result of collective injury to substantial numbers or proportions of cells.

The observed effects depend on the radiation dose and can be expected to have a threshold for the clinical deterministic effect.

Investigations of the non-stochastic effects in the 1985-1991 period concentrated on:

1. The pathogenesis of non-stochastic effects;
2. The level of threshold doses, their dependence on exposure conditions and their individual variability;
3. The influence and eventual interaction of different environmental factors;
4. The development of computer aided techniques for improved diagnosis of over-exposure;
5. The application of growth factors to stimulate the recovery of haemopoiesis;
6. The investigation of damage to the foetal brain at low doses;
7. The diagnosis and treatment of localised over-exposure;
8. The effect of internal emitters in utero and during neonatal development;
9. The decorporation of internally deposited radionuclides.

The programme has, since its onset, supported research into the treatment of radiation accident victims, and has intensified this work in the frame of its revision (1988-1989). Accidental exposure of large parts of the body occurs very rarely, but, as Chernobyl has shown, can then affect a significant number of persons. Accidents involving local exposure, particularly of the skin and underlying tissues, occur more

often than those exposing large parts of the body. Moreover, chronic skin exposure is a typical hazard in many industrial and medical nuclear manipulations. On the other hand accidents at the workplace involving incorporation of substantial amounts of radionuclides can make the removal of some of this material by pharmacological or mechanical means necessary. Such patients require a multidisciplinary management in which the degree of damage has to be assessed early.

Another area of particular concern in radiation protection, as a consequence of the observations of mental deficiency in persons irradiated in utero with relatively small doses during the atomic bomb explosions in Japan and of the claims of an increase in childhood leukaemia near nuclear installations, is the action of radiation on the developing organism. This field is very important because of the potentially greater radiosensitivity of dividing and differentiating cells. However, besides the above mentioned tissues; the effects for other developing tissues, such as endocrine organs, as well as the transfer of certain radionuclides to the foetus and the infant also are still insufficiently unknown.

A report making an association between an increase in cancer incidence in children and the preconception exposure of the fathers who were working in a nuclear facility, and continuing reports dealing with the association between exposure during intra-uterine development and childhood cancer emphasise the fact that radiation protection of the developing organism remains a high priority subject. As a consequence, and in response to a recommendation made in the 1985-1989 evaluation, the distribution of the research in the different sectors was modified at the end of 1989 and the work formerly carried out under "Acute Effects" has been divided up into the sectors "Non-stochastic Effects" and "Radiation Effects on Developing Organism", thus giving more emphasis to the developing organism.

III.B. SCIENTIFIC ACHIEVEMENTS

III.1. STOCHASTIC EFFECTS OF RADIATION

The most important stochastic effect induced by radiation is cancer, the probability of which is assumed to increase in proportion with the radiation dose at low doses without a threshold. The understanding of the molecular and cellular nature of cancer has made substantial progress in recent years and it is generally accepted that the disease arises as a multi-stage process involving mutational events caused by damage to DNA. Radiation induces a wide variety of damage to DNA which can lead to mutations, chromosomal aberrations and cell death. In addition to causing cancer when the damage occurs in somatic cells, when it occurs in germ cells the damage may be transmitted to future generations as hereditary defects. Research concentrates on the molecular and cellular consequences of radiation damage to DNA in an attempt to provide a better understanding of the mechanisms of radiation action, to gain more insight into how the cellular effects lead to malignancy, and to increase confidence in the radiation risks estimated for low doses of radiation.

The stringent budget conditions of the past few years meant that research priorities were concentrated on effects in eukaryotic cells to the cost of some previously supported research in prokaryotes. However, a well balanced, if somewhat restricted, choice of projects was achieved as the programme progressed.

The research carried out is relatively basic, but it is all aimed at providing a better knowledge of the shape of cellular dose-effect relationships to define the most probable extrapolation function for risk determination. The most probable extrapolation relies on the interpretation of radiation action at the cellular level using biophysical models and extending the interpretation to animal and human data. An understanding of the mechanism of radiation action at the molecular and cellular level is germane to the whole aim of radiation protection research.

III.1.1. Microdosimetry and biophysical modelling

The fields of microdosimetry and biophysical modelling have been an important part of radiation protection research for a considerable time and will continue to be so as there is no alternative to theoretical models for fully understanding radiobiological mechanisms or interpreting the effects of low doses. It is important to note that biophysical modelling requires both biological and physical input data and that the Programme is involved in obtaining this data. The calculation of track structure, the spatial pattern of energy deposition, for different types of radiation is a time consuming computer task which has been rigorously developed to make use of the rapid parallel computers. The computer codes have been further developed to include complex target geometries that has enabled the simulation of realistic three-dimensional bodies like DNA coiled histone, and in addition the codes can also take into account the fate of the chemical species which are produced in the different energy deposition events. In a collaborative contract two different approaches to extend the applicability of the computer codes from the gas phase to condensed state biological material have been initiated. A sensitivity analysis was made of the model parameters in order to understand their significance and the influence of different irradiation conditions. First steps towards integrating biophysical models with a model for carcinogenesis have been taken. Recent work extends the models from the initial spatial pattern of energy distribution through the induction of DNA double strand breaks to the formation of chromosomal aberrations. The work has shown that there are basic differences in the biological nature of primary events in mammalian cells produced by high and low LET radiation and that the biological effectiveness of different types of radiation can often not be precisely described by one physical parameter but that the combination of primary effects at three structural levels defines this effectiveness. Practical experiments using different accelerated particle beams have shown that different particles having the same Linear Energy Transfer (LET) have different efficiencies for the same dose for cell survival and mutation induction. These results have important implications for the biophysical modelling.

Another collaborative group addressed the question of specification of radiation quality at the nanometre level using calculational and experimental approaches. A sophisticated experimental set-up was built which enables measurements to be made

of the ionisation distributions in gases near the track of charged particles in the range from a few to several tens of nanometres (simulated distance). The analysis of the suitability of single radiation quality parameters to represent track structure has shown that the restricted LET is very suitable for a wide range of radiations and cellular effects. The single parameter radiation quality specification is not only of principal interest, but also of potential practical consequence if this parameter is measurable by methods suitable for routine use.

In practical radiation protection increasing use is being made of the low pressure proportional counters originally developed for research in microdosimetry for the measurement of mixed fields of radiation and the estimation of the radiation quality of the fields. The development of the low pressure counters for research has concentrated on techniques to reduce the size of the simulated volumes from microns to nanometres following the experimental indication that targets of nanometre size are important for the biological effect. These techniques are difficult, however, slow but consistent progress is being maintained.

III.1.2. Repair of DNA damage

The normal cell's ability to repair a wide variety of radiation induced DNA damage and, in so doing, reduce the severity of the radiation effect, is of direct relevance to the shape of dose-effect relationships and to a knowledge of the critical types of DNA damage. In recent years the study of repair has concentrated on mammalian and human cells making use of repair deficient cell lines associated with hereditary disease and mutant rodent cells. The inherited syndrome, ataxia telangiectasia (AT) is associated with severe radiation sensitivity and it has been shown that these cells are deficient in the correct repair of DNA double strand breaks. Several repair deficient rodent cell lines have been isolated, some of which are deficient in the repair of DNA double strand breaks and have characteristics reminiscent of AT human cells. The application of molecular biology techniques continues to provide more detailed information on repair genes in different species and on DNA repair rates in different parts of the genome. The continued development of these techniques will certainly lead to important advances in our understanding of the molecular nature and cellular consequences of radiation damage and repair.

The coordinated group working on repair, which is one of the best in the world, has isolated and characterised several human repair genes during the past few years making use of mutant cell lines. The analyses of these genes has revealed that the repair genes have been strongly conserved during evolution and a new method to isolate human repair genes has been developed which looks for homology between known repair genes in lower organisms, such as yeast, and human DNA. Homology between repair genes has been found in yeast, drosophila, mouse and man. Striking results have been obtained with regard to the existence of a non-random distribution of DNA repair over the human genome. It has been found that DNA lesions can be preferentially removed from actively transcribing genes and preferential repair is also found to be associated with the DNA strand which is read in the transcription process. The implication of these preferential repair processes for mutation induction are currently under investigation.

Cell free systems have been developed which permit an investigation of the repair of specific restriction enzyme induced DNA double strand breaks and a study of the conditions and composition of the extracts which are required for repair. A specific protein has been isolated from rodent cell lines which has many characteristics of the rec protein which is required for recombination in bacteria. Molecular biological techniques have also been used to investigate the nature of the DNA damage which results in mutations and shuttle vector methods have revealed that both point mutations and large deletions are induced by radiation, although large deletions predominate. This result was confirmed by an analysis of a specific mutation induced by a variety of DNA damaging agents which showed that radiation induced larger changes in the DNA of the specific gene than did a chemical mutagen. Little difference was found in the spectrum of mutations induced by gamma-rays and alpha-particles. The restriction fragment analysis method which indicated that many of the mutations induced in the HGPRT gene is being complemented by polymerase chain reaction (PCR) methods which permit a more detailed examination of smaller DNA base changes along stretches of the HGPRT gene and a more detailed examination of the mutation spectrum induced by different radiations.

III.1.3. Cytogenetics and cell radiobiology

The induction of chromosomal aberrations by ionising radiation is the most visual indication of DNA damage in the nucleus of the cell and the aberrations are associated with DNA repair, mutagenesis and malignancy. It is generally accepted that double strand breaks induced in the DNA backbone of the chromosomes are the lesions which lead to aberration formation although the actual mechanisms by which the various aberrations arise has not yet been elucidated.

A study of repair kinetics in relation to aberration formation in human lymphocytes using a repair inhibitor and the technique of prematurely condensed chromosomes (PCC) revealed a reduction in the yield of aberrations in the first 30 minutes post-irradiation. The frequency of chromosome breaks decreased with time whereas the frequency of dicentrics remained rather constant with time suggesting that the dicentrics are formed very rapidly after irradiation. This result is unanticipated and certainly needs to be reproduced in an independent laboratory, if confirmed it has important implications for the mechanism of chromosomal aberration formation. The use of specific restriction enzymes to induce DNA double strand breaks in comparison with the effects of radiation has contributed to the identification of this lesion as an important precursor of aberrations. The technique has serious restrictions from the point of view of quantifying the numerical association between DNA double strand breaks and chromosomal aberrations but it has provided information on the relative efficiency with which blunt ended DNA double strand breaks and overlapping ended DNA double strand breaks give rise to chromosomal aberrations.

Adaptation is the process whereby a small priming dose to a stimulated lymphocyte culture appears to make the lymphocytes more resistant to the induction of aberrations by a challenging dose applied a few hours after the priming dose. Investigations of this process have revealed that it is not due to a preferential killing

of sensitive cells nor due to a diffusible factor and that an inhibitor of poly ADPR-polymerase reverses the adaptation. The adaptation response seems to vary between donors and with time in the same donor but the reasons for this are not known. The adaptation response is now being investigated using a technique based on the reproducible pattern of DNA replication which permits the position of a cell in the cell cycle at the time of irradiation to be accurately defined so that cohorts of cells irradiated at exactly the same part of the cell cycle can be independently scored.

A collaboration between five laboratories has examined the shape of the dose-effect relationship for dicentrics induced in human lymphocytes at very low doses where large numbers of mitotic cells have to be scored. Problems of donor variability and some inter-laboratory differences were encountered and the exercise demonstrated the great difficulty of scoring the very low levels of induced chromosomal aberrations at very low radiation doses with any degree of confidence. The results for X-rays can be analyzed as being compatible with a linear extrapolation to zero dose although the measured yields of dicentrics up to a dose of 9.65mGy were less than the yield measured at zero dose so that a small threshold dose cannot be excluded although conventional theoretical wisdom would not anticipate a threshold for a stochastic effect. Recent measurements of the effect of low doses of neutrons indicate a linear dose response with the neutrons being some 25 time more effective than the X-rays at very low doses.

Recently a new technique, "chromosome painting" based on in situ hybridisation with DNA probes for specific chromosomes, has been developed which permits a very straight-forward scoring of translocation type aberrations. A striking result which has been measured with this technique is that about three times as many translocations as dicentrics appear to be induced by radiation in contradiction with theoretical predictions and many of the translocations involve very small pieces of the chromosomes ie.micro-translocations are found. This technique will have far reaching implications for biological dosimetry and may reduce the need for the use of flow-cytometry which has been developed to score dicentrics and micro-nuclei automatically, unless the chromosome painting technique can be developed for chromosomes in suspension.

III.1.4. Cell transformation

Cell transformation systems have been developed to provide a method to study the conversion of cells to a malignant state by radiation and other DNA damaging agents. Although unable to reproduce the development of cancer in an animal certain steps in the carcinogenic process can be followed such as the effect of dose, dose-rate, and radiation quality. One system, Mouse fibroblast cells can be used to obtain quantitative data although it is known that this system may not be representative for normal diploid cells. Using this system it has been shown that transformation frequency decreases with decreasing dose rate and with fractionation of gamma-rays but no effect of fractionation or decreased dose rate for alpha particles was found. This is as might be expected from conventional radiation biology but an "inverse dose rate effect" has been found by American workers for neutron irradiation where the transformation frequency increased as the dose rate

decreased. These results have not been reproduced in Europe where no dose rate effect for neutron irradiation was found in stationary cells with a small indication of an inverse effect in dividing cells which could be explained using a mathematical model by assuming that there are cell cycle variations in sensitivity to transformation .

A collaborative group of six European laboratories have been investigating the possibility of using the mouse fibroblast system to measure cell transformation at low radiation doses and have systematically studied the different steps in the experimental method which can influence the frequency of transformed clones measured in an experiment. A considerable amount of work has led to the compilation of a catalogue which defines the optimal methodology and identifies the morphology of the different classes of scoable transformed clone found in the system. The amazing conclusion from this work has been the realisation that although this system has been in use for many years a careful analysis of the methodology has never been made and no well defined protocol for the use of the system has ever been prepared.

Other studies have concentrated on the development of new cell transformation systems having more relevance to human cancer but it has proved difficult to transform human cells of either fibroblast or epithelial origin even though primary cell cultures from a variety of human tissues have been investigated. Recent work has concentrated on the use of established human cell lines which have been immortalised by transfection with viruses or oncogenes and on the role of tumour suppressor genes in cell transformation.

III.1.5. Animal carcinogenesis

Research using animals to investigate the induction of cancer by radiation have declined in recent years because it is expensive and not very popular, but several critical questions remain unsolved and unanswerable using cell transformation techniques. The trend in animal experiments has shifted away from the large classical type of experiment to smaller more specific experiments and much use is being made of molecular biological methods to study early events in the carcinogenesis process.

The use of the CBA mouse to investigate radiation induced myeloid leukaemia provides an excellent example of how first class research can uncover important steps in the development of the malignancy. Dose effect relationships for the induction of the myeloid leukaemia have been established for low LET radiation and the decreasing effect of decreasing dose rate has been demonstrated. Comparable dose effect relationships have been established for neutron exposure and it has been shown that there is no observable dose rate effect for the neutron exposures. Cytogenetic investigations of bone marrow cells from the affected mice commonly show specific changes in chromosome 2 at what might be "fragile sites" and molecular studies are revealing that the DNA at these sites has a special sequence which includes an inverted telomere like region. There are indications that, within the inbred and assumed homogeneous population of mice, four separate sub-

populations can be identified one of which seems particularly prone to the induction of leukaemia. All these results are especially interesting because of the increasing evidence of the role of "tumour suppressor" genes in both animal and human cancer and the fact that the "recessive nature" of the tumour suppressor hypothesis suggests that there may be reason to expect that genetic background may play a role in cancer susceptibility. Future work in animal carcinogenesis will have to take account of the role of genetic background in cancer susceptibility and define the experimental animal population carefully from this point of view.

The study of osteosarcoma in mice was started to provide relative information about the induction of bone sarcomas in man from ingested radium isotopes, the dial painters and the thorotrast patients, but has been developed to an investigation of the role of retro-viruses in the cancer process and the identification of mutated tumour suppressor genes in the tumour cells. The study has also shown that the incorporated alpha-particle emitting radium isotopes can also cause leukaemia in the animals giving a similar result to that found in the humans. In the bone tumours induced in the animals, research has looked into the integration sites of the viruses in the genome of the tumour cells and into the rearrangement and mutation of certain oncogenes although no consistent pattern of integration or oncogene expression could be found. More recent work has shifted to an examination of mutation in the p53 tumour suppressor gene in the osteosarcomas with more success.

The analysis of experimental data on animal carcinogenesis is being refined to improve the use of modern mathematical methods and to standardise the types of analysis used. The newer techniques are looking for ways to combine the time dependence of occurrence of tumours in animals after exposure with the dependence of the tumour frequency on radiation dose to optimise the use of the information available. Computer software has been developed to facilitate a unified approach to the mathematical analysis and it is intended that these newer analytical methods will be used to reassess the results of previous animal experiments currently being brought together in a standardised data base through the efforts of EULEP.
Considerable developments are currently taking place in the understanding of the process of radiation carcinogenesis and research on the molecular nature of radiation-induced cancer remains one of the most promising and intriguing areas of prime importance for low dose risk assessment. At the same time, information gained from these studies of radiation-induced cancer is likely to be important for the understanding and prevention of cancer in general.

III.1.6. Radiation effects in germ cells

No indication of hereditary effects in the offspring of atom bomb survivors has been confirmed although the data permit an upper limit on risk to be defined. Experiments on insects, plants and animals have long indicated the potential of radiation to induce hereditary effects and there are, therefore, good reasons to continue to study the induction of these effects in animals.

A study of the induction of both dominant and recessive mutations in male germ cells of mice indicated that many more recessive mutations were induced than dominant and that the doubling dose was not the same for different mutations in contradiction with what has previously been assumed. The study also indicated that the doubling dose determined for recessive mutations in the mouse could not be extrapolated to the doubling dose for dominant mutations in man. In addition the study showed that there were strain differences in sensitivity when the induction of recessive and dominant mutations were determined in four different mouse strains and this serves to indicate the difficulties which need to be anticipated in making extrapolations for risk estimates from animals to man.

Translocations induced in spermatogonia of mice are readily detectable cytologically and have provided much information on the shape of the dose effect relationship and how this is dependent on the biology of spermatogenesis. Using fractionated treatments and combinations of chemicals and radiation it was shown that differences in the dose effect relationship in different strains of mice depended on the proportion of sensitive cells in the spermatogonia and not on the cellular sensitivity to radiation.

In a study of non-disjunction in mice carrying marker chromosomes an indication that chromosome imprinting, revealed when it is found that a complete set of chromosomes is not in itself adequate for normal foetal development but the parental origin of the chromosomes is important, was occurring. Chromosome imprinting may be involved in many abnormality syndromes in man and in the occurrence of certain cancers and this is a significant finding.

Much human disease, such as allergy or blood pressure, which, while not obvious at birth as a genetic defect, develop later in life and have a hereditary component although it is clear that other factors (age and environment) can influence the severity and extent of the disease. The approach to take into consideration the potential role of radiation exposure on the incidence of these diseases is new and has implications for the assessment of the genetic hazard of radiation. The study of the spontaneously arising genetic and partially genetic disorders in man is providing valuable background information for making risk assessments but the philosophy of risk assessment will need to be modified to take into account, not only the effect of radiation on the induction of new mutations in germ cells for these diseases with a partial genetic component but also the fact that these diseases do not constitute a serious genetic disorder at birth but only manifest themselves as life threatening at later times.

III.1.7. Metabolism and effects of radionuclides

An accurate assessment of the risks of incorporated radionuclides depends on a thorough knowledge of the metabolism and dosimetry of the radionuclides, as well as of the associated biological effects.

Metabolism, tissue dosimetry and effects of incorporated radionuclides are of particular interest for the radiation protection of workers and the public, and

experimental studies have concentrated on developing better models and improved parameters for deposition, clearance and dosimetry of radionuclides in the respiratory tract. These observations, some of them obtained from man, allow not only a better assessment of the risks of inhaled radionuclides but also help to understand the behaviour of other inhaled pollutants.

Dosimetry of bone-seeking radionuclides and related studies on the incidence of osteosarcoma have given information on the possible target cells for osteosarcoma and leukaemia.

Finally, several multinational projects have tested newly developed compounds for decorporation of accidentally incorporated radionuclides. For the transport of radionuclides and decorporation treatment, an understanding of the binding properties is indispensable for an effective removal of radionuclides from the body. Research in this area concentrated on actinides because of their importance in the workplace. Treatment with decorporating agents can reduce the burden of radionuclides in target organs and this should reduce risks of cancer or non-stochastic damage. Currently, DTPA is the substance of choice for treating workers overexposed to plutonium and americium. Preliminary studies with 3,4,3-LIHOPO carried out under the CEC-NRPB Association Agreement 1990-92 have shown that it can be substantially more effective than DTPA for enhancing the excretion of plutonium after inhalation as nitrate and tributylphosphate, and after its intravenous injection as citrate. It is at least as effective as DTPA for americium. Preliminary studies have also shown that LIHOPO also mobilises thorium deposited in the lungs. This is important since no effective treatment for inhaled thorium is presently available. LIHOPO could represent an important development in the reduction of risk of late effects from intakes of plutonium, americium and thorium. At present importance should be given to the toxicology studies of LIHOPO. The toxicity of LIHOPO with particular emphasis on pathological damage to the lungs, liver, kidneys and gastrointestinal tract and its effect on the excretion of essential trace metals are already being evaluated. Studies concerning the biochemical kinetics of LIHOPO are planned for the near future.

III.2. NON-STOCHASTIC EFFECTS OF RADIATION

For many years the acute effects of radiation were in the foreground of research interest, probably due to the immediate impact of the atomic bombs exploded over Japan. Many investigations dealt with physiological, biochemical, and pathological changes after such exposure and the means to protect against them. During the thirty years under consideration, attention given by research and public concern shifted more and more from acute to late effects of radiation. Research concentrated on the general pathogenetic mechanisms of non-stochastic effects and, especially, in those tissues of relevance to practical radiation protection: brain, heart, skin, lung, thyroid and the lens of the eye. Investigations concerned the establishment of the threshold doses for damage, the elucidation of the pathogenic mechanisms involved and the methods to recognise, prevent or treat non-stochastic damage. Particular attention during this period was given to the haemopoietic-immune system, to skin and to the developing organism.

III.2.1. Acute and chronic effects on the haemopoietic system as a consequence of accidental exposure of large parts of the body

During the past 5 years, procedures for diagnosing the severity damage after exposure of large parts of the body have been improved by further developing cytological, cytogenetic, cyto-fluorometric and biochemical tests. Research has provided new methods for preparing cell grafts and for applying conditioning treatment for bone marrow transplantation. Specific factors that stimulate bone marrow recovery have been prepared and characterized; these should become useful for the treatment of accident victims. Studies in animal models have improved our understanding of the pathogenesis of early and long-term damage and recovery of the different haemopoietic and immune components in the body.

III.2.1.a. Treatment of radiation accidents and underlying pathogenetic mechanisms

The studies carried out in the programme dealt with problems related to bone marrow transplantation as well as the pathogenetic mechanisms involved in the regulation of bone marrow replacement and stromal cell support.

The diagnosis of haemopoietic damage after acute and fractionated whole or partial body exposure has been investigated in monkeys and patients. The data show that the usefulness of chromosomal aberrations as indicators after inhomogeneous exposure is limited, and that increases in amylase, cortisone and ACTH are characteristic for radiation exposure but may not give quantitative information on the damage except in very specific situations. The radiosensitivity of different haemopoietic progenitor cells was also determined for different growth factors used for stimulation. A comparison between stem cell loss and bone marrow failure, based on published data, indicates that larger species are less tolerant to the depletion of stem cells than smaller ones. The stromal fibroblast forming units (CFU-F), which are probably identical to the cells forming the ossicles, represent an important factor in the micro-environment of the bone marrow.

Long-term recovery was investigated with respect to stromal cells and the different stem cells, in particular, with respect to the relation between haemopoietic and stromal recovery. From this it appears that stromal recovery occurs without persistent defects after doses up to 10 Gy.

To maintain cultures at an undifferentiated state for further transplantation, restriction of differentiation with different growth factors was studied thoroughly, but the problem has not yet been fully solved. Another study dealt with the conditioning of the host prior to transplantation. Monoclonal antibodies given as a single agent didn't give sufficient results. Other methods were developed to produce and purify lymphokinine to suppress the lymphocytes that cause the graft vs host reaction. The results are promising.

In a study in 1990, aiming to improve therapeutic approaches after irradiation, 30 patients that received total body irradiation of 1000-1400cGy, were treated with

autologous bone marrow transplantation, and received blood stem cells (autologous). The comparison of bone marrow versus blood derived stem cells showed that the use of blood derived stem cells results in an earlier recovery of haemopoiesis than bone marrow derived stem cells. During the same period a preparative method used to isolate stem cells by positive selection based on binging to CD34 antibodies and the use of the resulting fractions for preclinical autologous as well as allogenic bone marrow transplantation in rhesus monkeys was established. Considerable stem cell enrichment (40-140 fold) with less than 1 % contamination of T lymphocytes (cells responsible for the graft vs host disease) has been achieved using this method. The method will be adapted to human treatment modalities.

A data base of Radiation Accident Case History is being established, including the Chernobyl cases in close collaboration with the Institute of Biophysics in Moscow. The database is called **precomputer case report (PCR)**. The evolution of biological parameters (blood cell changes) within 3-5 days after irradiation could indicate if substitutional treatment is required, but it does not allow dose assessment. Biomathematical models need to be developed in order to calculate remaining stem cells after irradiation. The response and tolerance of the canine haemopoietic system to partial body and inhomogeneous exposure was investigated on the basis of in vitro assays of the various progenitor cells. An exposure of 30% of the marrow does not greatly affect blood granulocytes and platelets. The data on whole body irradiation showed a large and long-term depression of erythroid stem cells. This is, therefore, the more radiosensitive cell among all haemopoietic elements investigated in different species. The data obtained were also compared with those from different radiation accidents and will help to establish an expert system to aid the management of such accident victims. A preliminary assay using 30 case histories (the group has access to several hundred radiation accident case reports), showed that this PCR is suitable to record in a systematic way those signs and symptoms, that develop during the first 60 days after exposure. The final aim is to develop a computerised data collection in order to be able to correlate early signs and symptoms with later clinical developments.

During this period a **systems engineering model of human granulocytopoiesis** was developed to calculate from the pattern of granulocyte changes in accident situations the number of stem cells that remained after total body radiation exposure and from which recovery could begin. Preliminary results show that if more than 6 per 10^6 calculated stem cell units were available, then a recovery is possible without stem cell transplantation. If the number is less, then an irreversible course is most likely.

III.2.1.b. Damage to the adult immune system

Radiation damage to the bone marrow and the immune system is the prominent feature after exposure of large parts of the body. It has drawn renewed interest after the Chernobyl accident. Bone marrow transplantation techniques were developed with the support of the programme. A change in the priorities in this area gave greater emphasis in this framework programme to long-term effects and mechanisms of damage, i.e. the relation between haemopoietic damage and leukaemia development, and the importance of immune cells.

The understanding of the complexity of the cellular and humeral immunological reactions as well as their interplay has made marked progress in recent years. This has largely benefited, and has even been promoted by, immunological studies on irradiated animals. Studies have shown that a synthetic nonapeptide when injected in mice immunodepressed by sublethal irradiation, induces restoration of T helper cell activity and IL-2 production. The immunorestorative activity of the nonapeptide is similar to that of the human recombinant IL-1 beta, but with no IL-1-like inflammatory effects which hamper the use of the whole protein as immunomodulator. The comparison of the protective and restorative activities of the nonapeptide and IL-1 beta on the 30 day survival of lethally irradiated mice showed that when the mice were given a single injection of different doses of the nonapeptide or IL-1 20hrs before TBI, both molecules were found able to increase the percent survival of mice exposed to 750 or 850 cGy, but not to 950 cGy. The nonapeptide, however, was less effective than the human recombinant IL-1 beta and displayed a different dose-response relationship, suggesting that the two molecules act through different radioprotective pathways. Even if the nonapeptide is less effective than the IL-1 beta, it does not have the IL-1-like side effects of the whole molecule, and therefore may be an interesting compound for medical intervention in radiation accidents. More work is needed to study these molecules.

III.2.1.c. Biological indicators of radiation damage

In the case of accidental overexposure, the doses and their distribution in the body are usually not well known. The determination of chromosome aberrations in cultured circulating lymphocytes appears to be the method for information on the degree of severity if the dose distribution is not too inhomogeneous. Flow cytometry was used to detect chromosomal changes either directly or after labelling of the centromeres with specific antibodies. Studies on human and rat blood samples using labelling of membranes followed by flow cytometry were unsuccessful in detecting radiation-induced changes due to the high inter-individual variability. A variety of potential radiation damage indicators are being investigated in the blood of radiotherapy patients. At present no methods other than chromosomal aberrations seem more than a remote possibility.

During the period 1990-1991, 29 leukaemia patients (AML, CML) were cytogenetically examined after total body irradiation (1200cGy) and chemotherapy and bone marrow transplantation with respect to bane marrow cell aberrations as a function of time after irradiation. The results showed that dicentric chromosomal aberrations persist for several years after such an exposure.

III.2.1.d. The effect of haemopoietic growth factors

Interleukin-3 (IL-3) is known to stimulate in vitro a bone marrow cell population. But administration of recombinant human IL-3 to monkeys, does not produce such an effect. However, larger effects were noted if IL-3 was administered with another, hemopoietic growth factor, granulocyte/macrophage colony-stimulation factor (GM-CSF). On the other hand the GM-CSF data essentially demonstrated that monotherapy with a hemopoietic growth factor is restricted by the number of

available target cells in that complete prevention of neutropenia could be achieved up to doses of 5 Gy total body irradiation.

Similar studies have been initiated and are still continuing with other growth factors and combinations of various growth factors. These studies indicate that radiation induced pancytopenia may be better treated by administering a combination of growth factors rather than monotherapy.

III.2.2. Radiation damage to skin and other underlying tissues

Accidents as a result of local exposure of skin and underlying tissue are more common than those involving whole body exposure. Such patients also require multidisciplinary management in which the degree of damage has to be assessed early in order to allow a treatment which restores function optimally and reduces late permanent damage.

Research has focused on better indicators for vascular, epithelial and deep tissue damage in order to predict the clinical consequences and accordingly guide the treatment of the patients. Several new treatment methods have also been explored, and the results of such research are already being applied for the management of accident victims. Several laboratories have joined their efforts in developing better radiation protection criteria for detrimental damage to skin and have studied various endpoints, including skin cancer and atrophy, in dependence of the penetrating ability and the field-size of the radiation exposure. Non-stochastic damage in other tissues has also been investigated and, for example, cataract caused by external and internal radiation exposure for medical reasons has been detected in epidemiological follow-ups.

Several physiological changes which precede other clinical symptoms, particularly blood flow, have been investigated with particular emphasis on the situation encountered after accidental exposure of the hand. Conservative treatment adapted to the particular situation has been developed, and the indications and modalities of surgical interventions removing ulcerations and potential or actual necrotic tissues have been defined.

As a complement to the investigations in patients, studies on pig skin have concentrated on the analysis of different modern methods to assess physiology, cytogenetics and biochemistry of the irradiated skin. Biochemical studies of serum proteins showed distinct differences between animals exposed to high or intermediate doses. The use of these methods should allow discrimination between ulcers and deep muscle damage which require surgery and those which do not.

Concerning the **radiation protection criteria**, skin and lens are the only tissues for which radiation protection takes account of the non-stochastic rather than the stochastic effects but, in the case of skin, this also depends on the size of the exposed area and the penetration of the radiation. Stochastic skin cancer was studied after uniform and non-uniform beta exposure of mouse skin. The dose effect relationship for uniform exposure in mice showed a nearly linear increase and

saturation at higher doses. Non-stochastic effects -desquamation and ulceration- was investigated in mice. Moist desquamation showed a marked dependency on the exposed area and the beta energy. To produce 50 % moist desquamation a dose >1,500 Gy of promethium betas is needed (at 0.3 mm^2) compared to 20 Gy for a large (100 mm^2) strontium-90 source. A detailed analysis of the reaction of pig skin to beta and alpha emitters showed that the target population is the epidermal basal cells and that the appearance of damage and its repair can be explained on the basis of cell cycle and radiosensitivity parameters. Two methods made possible the definition of two thresholds for muscle radiosensitivity: about 30-40 Gy for direct necrosis and 10-20 Gy for the limits of delayed fibrosis extent in spontaneously healing radiolesions. After early removal of irradiated skin, the fibrosis extent is the underlying tissues is limited to tissue given above 25-30 Gy.

III.2.3. Radiation effects in the lens, the thyroid and the lung

A substantial number of people show various pathological changes in the eye. Whereas eye pathology appears to occur independently of the radiation dose and is thus related to the underlying disease, more cataracts were seen in patients who had received more than 10 Gy than in those who had received smaller doses.

Cultured cells from dog thyroid are a useful model to study cell proliferation and differentiation as well as the action of growth factors on these parameters. In order to study damage to the thyroid, a model of human thyroid cell line has been developed by immortalizing cells by human papilloma virus genes. The cells obtained are similar to primary human cell culture with epithelioid morphology, thyroglobuline secretion and stimulation by thyrotropin but not the mitogenic response to TSH. The cell line degenerated thereafter (after 120 generations they completely dedifferentiate) but these experiments show that such a development is possible. Two models of transgenic mice developing differentiated and dedifferentiated thyroid tumours have been developed. These models which are independent of any pharmacological treatment are the best for the in vivo study of radioiodine induced carcinogenesis. An assessment of dose to the fetal brain after incorporation of ^{131}I has been performed. Only gamma rays should reach the brain. Concerning risk estimation, the average number of cells per gram of tissue is an important parameter.

Alveolar macrophages (AM) harvested by lung lavage were studied in mice lung after inhalation of $^{239}PuO2$. The results draw attention to the crucial role of AM in handling of Pu deposited in the lung (e.g. large amounts of Pu deposition affect epithelial lung cells, increasing proliferation of type II cells and causing hyperplastic changes).

III.3. RADIATION EFFECTS ON DEVELOPING ORGANISM

Radiation protection of the developing organism remains a high priority subject. The consequences of an irradiation in utero or during childhood, have been studied in several animal models. The aspects meriting most attention are radiation-induced cancer and damage to the developing central nervous system. Morphological and

biochemical parameters of brain development after exposure in utero has been yielding information on whether or not the mechanisms of action are compatible with the assumption of a threshold dose for such effects.

III.3.1. The cultured embryo model

The mechanisms by which cell damage can be induced during pregnancy and how some of it can be transmitted to the foetus and newborn has been investigated in cultured mouse embryos. The results have great relevance for radiation protection because they indicate that radiation can damage the preimplantation embryo to give malformed neonates and not just kill it outright as has been assumed before. These data have yielded information on the transmission of genetic damage from the embryonic period to the newborn.

III.3.2. Brain and haemopoietic damage

Observations of an increased incidence of mental deficiency and a decreased intelligence quotient in children born to mothers exposed especially during the 8th-15th week of pregnancy have raised the question whether a threshold dose exists for this effect. It appears impossible to answer this question from human data only, unless one understands the pathogenesis of this type of damage. Although animal models are still far from modelling human intelligence, new approaches based on quantitative image analysis of morphological and biochemical alterations and more refined biochemical and physiological tests have made animal models increasingly more useful.

Investigations on the **central nervous system** have given interesting information on potential mechanisms but have not so far been able to help to decide whether or not a threshold exists for these effects.

In irradiated rats during the principal period of cerebral organogenesis on day 15 postconception, glia changes which were prominent after high level exposure of the adult brain seem less significant after in utero exposure. Biochemical investigations of a variety of neurotransmitters and their receptors did not show marked alterations.

The question of whether in utero exposure delivered at a low dose rate also damages the developing brain is of considerable importance in radiation protection. Exposure of mice or rats to low dose rates at different times of pregnancy showed only a small reduction of relative adult brain weight dependent on dose and dose rate. Malformations were observed only at dose rates above 4.75 Gy/day, particularly on day 15. A second series of experiments were carried out to assess the possible influence of low dose rate on brain development. Gamma and X doses of 0.25 Gy given on day 15 post conception (p.c.) at various rates ranging from 1 Gy/day produced a similar level of brain atrophy of about 4 %. Moreover, there was persistence of radiation effects (2.5 %) after protracted doses over 4 days (from day 12 p.c. to day 16 p.c.).

Some studies were focused on the evaluation of the risks of low dose rate exposure protracted over a number of days during pregnancy. No data were available on this topic. The results showed that protracted exposures to gamma rays during selected periods of the pregnancy produce brain alterations after dose levels (as low as 20 cGy) previously thought to be damaging only under acute conditions. Additional experiments to detect a threshold in such conditions revealed that a careful selection of the period of irradiation during the pregnancy, namely by irradiating between day 12 and day 16 post-conception, produces a brain atrophy nearly as important as the one caused by an acute exposure to the same dose given in 20 seconds during day 15 post-conception. The dose effects on the brain did not show anymore after exposures to 5 or 10 cGy of gamma rays even when given during the most sensitive period of the corticogenesis (day 12PC to day 16PC). The threshold must be located somewhere between 10 and 20 cGy for the brain weight endpoint. A future project is to see the effects of protracted exposures to 4-10 cGy of neutrons.

In the developing **haemopoietic system**, no exceptional radiosensitivity of stroma or immune cells has been observed.

Mice contaminated with ^{241}Am were investigated on the basis of long term bone marrow cultures. Both haemopoietic and stromal cells are radiosensitive and potential target cells for early and late effects after in utero contamination, but stromal cells may play a more important role in the foetus. A large percentage of the contamination occurs during lactation. The distribution of ^{241}Am in the foetus differs from that in the adult.

III.3.3. Carcinogenesis in the developing organism

Studies on carcinogenesis in liver and brain did not reveal any important synergism of radiation with chemical carcinogens in foetal and infant mice. Recently more studies are being developed on models related to childhood leukaemia following reports claiming increased cancer incidence in children following exposure of the fathers. The study in animal models on the development of neoplasias of haemopoietic and osteogenic tissue after exposure in utero to ^{239}Pu is making good progress, but is a long-term experiment, thus too early to see a significant pathology in the animals.

III.3.4. Studies on transfer of radionuclides in utero

Progress has been achieved in the investigation of transplacental uptake of maternal ^{239}Pu contamination at mid-term gestation. Approximately 1% of the ^{239}Pu appears in the newborn offspring - most of this in the fetal liver. When contamination occurs early in gestation, uptake in the newborn is ten- fold lower. The objective to develop dosimetric models and assessment of risk for in utero exposure is making good progress.

III.4. POST-CHERNOBYL ACTIONS

Following the Chernobyl accident the programme has defined additional research requirements, re-oriented some existing research contracts and started some new contracts. Out of the ten urgent actions, three dealt with biological effects: Post-Chernobyl action VIII. Improvement of practical countermeasures: preventive medication; IX. Treatment and biological dosimetry of exposed persons; X. Feasibility of studies on health effects due to the reactor accident at Chernobyl.

Action VIII. IMPROVEMENT OF PRACTICAL COUNTERMEASURES: PREVENTIVE MEDICATION

Radioactive iodine isotopes, in particular ^{131}I, represent a major constituent of radioactive releases. Radioiodine is preferentially taken up by the thyroid and can increase the risk of thyroid cancer. When the dietary intake of iodine is low, then the uptake of radioiodine by the thyroid and therefore the risk is larger. The risk from treatment with stable iodine also depends on dietary intake; it is higher where the intake is low, and is also higher in the sick and the elderly.

The aim of this action was to improve the evaluation of risks of radioiodine release for the population, of iodine treatment, the criteria for preventive treatment of a whole population, and the definition of a protocol for the treatment of patients having ingested radioiodine. It has enabled the various levels of thyroid radioiodine exposure in the different regions of the Community and in infants of pregnant mothers, the risks of iodine prophylaxis after a nuclear accident and the efficiency of iodine administration after radioiodine ingestion and thyroid uptake. The collected data on radioiodine uptakes can now be used to set decisions criteria for iodine prophylaxis after a nuclear accident.

Several recommendations were formulated: 1. Before any nuclear accident: generalisation of iodine prophylaxis; 2. After a nuclear accident: immediate ban on the consumption of contaminated foods (especially milk); generalised iodine treatment with its risks of hypothyroidism in foetuses and infants and hyperthyroidism in goitrous people should be avoided. Iodine prophylaxis should be administered to pregnant women, neonates, infants, children and adolescents up to 16 years old; 3. After thyroid radioiodine exposure: iodine should be administered a posteriori to the categories defined in 2 if radioiodine has been taken up by the thyroid.

The results of the action emphasise the fact that our knowledge is still inadequate for the elaboration of a rational strategy on the prevention of radioiodine induced thyroid cancers and that further studies are needed in this field.

Action IX. TREATMENT AND BIOLOGICAL DOSIMETRY OF EXPOSED PERSONS

Diagnosis and care of radiation accident victims

Research in this area has aimed to improve the methods to establish the risk of the individual patient to develop fatal radiation syndrome.

The biological indicators available at the time of the accident were lowered peripheral blood cell counts, the severity and rate of development of clinical sickness shortly after exposure, and increased chromosomal abnormalities. Following the accident the predictive value of these indicators were reanalysed. Methods based on genetic damage in circulating cells to evaluate biological damage after an accident have been improved by introducing more efficient and rapid tests and by providing procedures to assess the degree of inhomogeneity of an exposure.

A new approach to biological prognostic dosimetry was initiated by studying the possible application of the new Hemopoietic Growth Factors (HGF) - eg. granulocyte/macrophage colony-stimulating factor (GM-CSF) and interleukin 3- for determining the amount of surviving stem cells of the blood-forming system. The response to the new haemopoietic growth factors was studied in cell cultures and in vivo in monkeys. These stem cells were activated and stimulated by the hormonal action of the HGF to produce progeny which was then reflected in the peripheral blood cell counts. A poor prognosis was indicated when administration of HGF did not result in a response meaning that too few stem cells that are survive.

Treatment with the HGF factors, possibly in combination with interleukin 3, is recommended soon after the exposure in all patients who are expected to develop pancytopenia. Such treatment will shorten the pancytopenic period and reduce the associated risks in patients who will eventually recover spontaneously. However, more studies are necessary to obtain information on the doses of HGF that are required for a substantial response, or which may cause toxic effects.

Prognostic value of HGF

An investigation was made to determine whether early post-irradiation treatment with GM-CSF might cause a detectable response of the peripheral blood cell counts and whether the capacity for endogenous hemopoietic recovery could be reliably determined by such a response. Indeed, GM-CSF can serve that purpose in the dose range between 4 Gy and 8 Gy total body irradiation. However, the variations are considerable and at least 8 days of observation are required for a reaction. Responses were not seen after doses greater than 8 Gy. In conclusion the data has shown that although an excellent correlation exists between GM-CSF response and radiation dose given, the GM-CSF response cannot at present be used as an indicator for radiation damage before about a week after irradiation.

On the other hand, the accident in Chernobyl has shown the limitations of bone marrow transplantation, at least, with the presently available techniques.

Biological dosimetry of exposed persons by quantitative analysis of chromosomal damage

Immediately after a nuclear accident there is usually an urgent need to provide an estimate of dose as quickly as possible. In practice, a dose estimate is not available until three or four days after receipt of a blood specimen. The Prematurely Condensed Chromosomes (PCC) technique, however, opens up the possibility of scoring aberrations (estimation of dicentric chromosomes) within a few hours of blood sampling. Nevertheless, the technique is new and requires further background information.

The Chernobyl experience was notable for highlighting several important features for biological dosimetry :

1. For highly over-exposed subjects, lymphocyte cultures yield a low mitotic index;
2. Accidental irradiation is usually inhomogeneous and this can often be detected cytogenetically;
3. The information obtained from the analysis applied to the dicentric distributions is of value as an indication that some proportion of the cells can be spared, implying that there is likely to be a natural recovery of bone marrow;
4. The assay based on prematurely condensed chromosomes should be investigated further.

Action X. FEASIBILITY OF STUDIES ON HEALTH EFFECTS DUE TO THE REACTOR ACCIDENT AT CHERNOBYL

The possible consequences of the accident particularly on children has been of great concern. Three independent laboratories have investigated whether any health consequences might be expected in the Community, and, whether they might be detectable by an epidemiological investigation. The conclusions of this feasibility study have been published in document EUR 12551.

The most sensitive radiation effect is probably the induction of childhood cancer and, as this is a rare disease which appears within a few years after birth, it would be most amenable to study. An epidemiological survey of childhood cancer is currently being carried out by the International Agency for Research on Cancer within areas where selected cancer registration was in existence at the time of the Chernobyl accident. The study will try to correlate the cancer incidence with the time of the accident and the place of residence of the mother during pregnancy.

III.5. SUPPORT TO SCIENTIFIC COLLABORATIVE GROUPS: European Late Effects Project Group (EULEP)

EULEP is one of the well recognised European collaborative groups which has had a positive effect on the development of modern radiation biology research in the Community. The group has determined that co-ordinated projects and interests

within the Commission are likely to be more effective than isolated projects in this area. Four Committees are continuously acting in standardisation and development of methodologies, task groups are co-ordinating co-operative research, and organising symposia to give stimulating opportunities to exchange ideas. Training activities in specific techniques allow an increase in know-how throughout the Community, but also exchange of young scientists which is building fruitful connections between countries.

Today, EULEP is facing a new challenge. Because of the new approach of CEC multi-national contract management, which increased the coordination of contracts, the role of EULEP has to be redefined. EULEP has to remain a meeting point of laboratories, willing to exchange know-how, methodologies, ideas, in order to stimulate creativity in radiation protection research. A periodic redefinition of task groups and task group convenors is needed to stimulate renewal and avoid routine. EULEP by its diversity has the ability to produce reference documents, such as the Atlas of Pathology, Decorporation Guide book, database of Animal Radiobiology Archives. Therefore, to avoid duplication of work with CEC Radioprotection activities, in the future well defined tasks should be formulated. A closer contact between EULEP Council and CEC representatives would help to implement new activities which will complement rather than parallel the ongoing CEC research contracts.

C. CONCLUSIONS AND PERSPECTIVES

Good progress has been maintained, in general, over the whole area of research covering biological effects, with outstanding results being achieved in some areas. The wider application of modern molecular biological techniques has opened new possibilities, undreamed of but a few years ago, for more detailed analysis of damage to DNA, its repair even at the DNA sequence level, and in the study of the early events in radiation induced cancer. Further exciting developments can be anticipated. New cytological techniques are being developed and perfected which, together with new methods for detecting DNA damage, will permit a better investigation of the way initial damage at the molecular level is converted to cytological effects and eventually cancer. The radiobiology of cell transformation remains a formidable task as the relevance of the classical fibroblast system for human cancer is doubtful and the epithelial transformation systems have not yet supplied good quantitative information. Biophysical modelling of cellular effects shows considerable promise for making predictions about the extrapolation of experimental data to protracted low dose risk.

The following important scientific achievements of the biological effects part of the programme deserve special mention:

- Exciting developments in the understanding of the early cytogenetic events in murine myeloid leukaemia;
- Considerable advances in understanding the molecular biology of radiation-induced cancer, in particular mutations occurring in the p53 tumour suppressor gene in murine osteosarcomas;

- Investigation of preferential repair of DNA damage in active genes;
- Computer simulation of the interaction of radiation tracks with three dimensional cell structures;
- Molecular analysis of the nature of radiation induced mutations;
- New possibilities for the treatment of accident victims using cell growth factors;
- Development of new compounds for decorporation of accidentally incorporated radionuclides;
- Detection of foetal brain atrophy in rats at doses as low as 0.25 Gy;
- Development of chromosome painting techniques for the study of stable chromosome aberrations.

In the light of these achievements, it is believed that the forthcoming programme should put emphasis on the following areas:

1. Biophysical modelling of radiation oncogenesis

There are increasing indications from molecular biological studies of the malignant process that two or more genetic alterations are associated with the conversion of a normal cell to malignancy. These studies have identified mutations in oncogenes and have led to the concept of tumour suppressor genes. Recent developments in the biophysical modelling of the radiation oncogenesis have taken advantage of these developments and use multi-stage mutagenesis models. The calculational methods for the development of these models to radiation are now available and they can be applied to analyze the results of animal experiments and epidemiological data. The objectives will be to stimulate the development of the models and apply them for the analysis and interpretation of animal and epidemiological data; to develop verification methods; to investigate the predictions of the models especially at low doses; to elaborate the implications of the models for prolonged exposure and for risk projection.

2. Molecular studies of radiation oncogenesis

Exciting progress is being made in the understanding and characterisation of the early events occurring in radiation induced animal oncogenesis. It is clear that specific cytogenetic changes are involved and that certain DNA sequences play an important role. One very significant finding is that in an inbred and apparently homogenous animal population four different groups can be identified using molecular biological techniques but radiation only induces cancer in one of the four groups. The other three groups of animals do not develop radiation induced cancer at the doses used. This has implications for radiation induced cancer in man, suggests variations in susceptibility to cancer in the population and may reflect on the problem of individual radiation sensitivity. The objectives will be to gain a better understanding of the early cytological and molecular events occurring in radiation oncogenesis; to investigate the genetic background associated with predisposition or sensitivity to radiation induced cancer; to determine whether radiation can induce cancer in the apparently resistant animals; to measure the dose effect relationship for cancer induced in the resistant animals, if cancer can be induced.

3. Transgenerational and in utero radiation effects

Ever since the epidemiological study of the childhood leukaemia cluster at Sellafield suggested an association between the exposure of the father and the occurrence of the childhood leukaemia there has been a need to establish clearly from a radiobiological point of view if there was a potential mechanism for the effect. There are some indications from Japanese studies that radiation induced transgenerational carcinogenesis can occur and preliminary results from one European laboratory show that mutagenic chemical exposure of fathers can lead to increased sensitivity to radiation induced cancers in the offspring but many questions remain to be answered.

The problem of low dose radiation effects on the developing brain still has not been solved and while there are indications from the Atom bomb survivors that in a sensitive period of gestation (8 - 15 week) radiation can affect the intelligence it is still not clear whether there is a small threshold dose or whether the effect behaves as a typically deterministic effect. Further research is needed to develop the sensitive methods which will be required to investigate this effect at low doses and low dose rates. In future, consideration should also be given to radiation sensitivity in periods of cell proliferation in organogenesis during foetal development in general.

The objectives will be experimental investigation on the possible induction of sensitivity or predisposition to cancer in the offspring of irradiated parents; molecular biological investigation of the genetic basis for any induced transgenerational carcinogenic effect, eg. new germ line mutations in tumour suppressor genes; development of refined physiological and patho-morphological techniques for the identification of low levels of damage in the foetal brain; a study of the effects of low dose, low dose-rate exposure of animal foeti in the sensitive period of gestation.

In the area of biological effects of radiation action, future research must concentrate on the extension of the use of the molecular biological methods and on the integration of all available information coming from biophysical modelling, cellular data, molecular carcinogenesis, animal experiments and epidemiology. A good understanding of all this will be needed if a rational choice is to be made of the appropriate methods of extrapolating effects at high doses to define the protracted low dose risk.

IV. RISK AND MANAGEMENT OF RADIATION PROTECTION

IV.A. INTRODUCTION

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IV. RISKS AND MANAGEMENT OF RADIATION PROTECTION

IV.A. INTRODUCTION

Risk assessment and risk management have an important role in the development and subsequent implementation of well conceived policies on health, safety and environmental protection. The adequacy of these policies and the efficacy of their implementation will depend, among other matters, on the reliability with which risk can be assessed and on the techniques or processes available for their evaluation and management. The successful implementation of the programme will lead to better risk quantification, better methods for its evaluation and communication and, consequently, a more optimal allocation of resources to health, safety and environmental protection.

An integrated approach was taken to evaluate risks to man from the utilisation or presence of ionising radiation, and an attempt was made to develop a consistent framework to place radiation in perspective with other risks. The aims of the 1985-1989 Programme were as follows:

1. To assess individual and collective doses in order to establish an overview of population exposure and its temporal and regional distribution;
2. To assess the detriment of ionising radiation by developing mathematical and conceptual models and by using epidemiological data from exposed populations;
3. To evaluate the social and economic implications of the use of ionizing radiation and alternative procedures with the aim of optimising the protection of man and his environment;
4. To develop methods to analyze accidents at the critical steps of the nuclear fuel cycle with respect to public health, economic consequences and appropriate countermeasures;
5. To assess risk in a comparative way by quantifying risks and the factors determining them;
6. To reduce exposure from medical diagnostic radiology.

In absolute terms the amount of research on risk management and optimisation of protection did not fully attain the level foreseen in the Programme proposal; compared to the other sectors, however, this research increased substantially. The Chernobyl accident stimulated interest in several areas considered in this sector and intensified the development of improved procedures for the assessment of the radiological consequences of accidents, of systems for off-site emergency management and the optimisation of countermeasures. With respect to the reduction of patient exposure, research on quality assurance increased, while that on referral criteria for diagnostic efficiency and efficacy remained limited, since the available efforts were concentrated only on some few selected measures for dose reduction.

The aims of the 1990-91 Programme remained the same as those for 1985-89 but some rationalisation was made and this was facilitated by the introduction of multi-partner contracts in 1990. The research in this area can be conveniently grouped

under the following sub-headings and progress and achievements made in both the 1985-89 and 1990-91 Programmes are discussed subsequently within this framework:

1. Epidemiological studies
2. Comparative risk assessment
3. Risk from exposure to natural radiation
4. Probabilistic accident consequence assessment
5. Decision support systems for off-site emergency management
6. Optimisation of protection (ALARA)
7. Reduction of patient exposure in medical diagnostic radiology.

IV.B. SCIENTIFIC ACHIEVEMENTS

IV.1. ASSESSMENT OF HUMAN EXPOSURE AND RISK

IV.1.1. Epidemiology

The analysis of data from human populations provide the most direct information on radiation risks but most of these data originate from people exposed to high doses at high dose rates, such as the survivors of the atom bombs or from patients treated with ^{224}Ra or thorotrast for medical reasons. Collection and interpretation of data from populations exposed to low doses, such as workers in the nuclear industry or people exposed to enhanced levels of radon are fraught with uncertainties. Co-operation on a Community scale is needed to obtain statistics of sufficient power and the recent introduction of multi-partner contracts has stimulated collaboration at the European and international level.

IV.1.1.a. Populations exposed to external radiation

The pattern of radiation-induced cancers in populations exposed to high doses can be modelled as a relative risk projection or as an absolute risk projection. It has been demonstrated that, in general, the data on solid cancers are consistent with a relative risk model with a tailing-off of risk with time rather than with an absolute model, which however gives a better analysis of leukaemia induction. Increasing attention is being paid to the problems of time projection after exposure and extrapolating risk between populations and this should lead to a more realistic assessment of the risks and their uncertainties.

Good progress has been made in the analysis of the data for Radiation Workers and a first result was recently published. This revealed that although there was a strong healthy worker effect when the analysis was made within the worker population a dose effect relationship for leukaemia was found but with large uncertainties. The statistical power of such a study can only be increased by combining data throughout Europe and internationally in the future.

IV.1.1.b. Studies on childhood leukaemia

The studies of childhood leukaemia have concentrated on three areas, the risk following irradiation in utero, the geographical distribution of childhood cancer in relation to nuclear installations, and the collation of childhood leukaemia statistics throughout Europe. The reassessment of the childhood cancer risk after in utero exposure has resulted in risk values for leukaemia and solid cancers which are in the same order as the recently re-evaluated risks derived from the atom bomb survivors. The study of cancer clusters has concentrated on deriving the best statistical methods to detect and analyze them and these methods are now being applied in various parts of Europe. The collation of childhood leukaemia statistics was started in response to the Chernobyl accident and aims to look for a spatial and temporal correlation in areas of high and low contamination from the accident in children born soon after the accident. Currently the background levels of childhood leukaemia in different countries in Europe for the five year period before the accident have been established.

IV.1.1.c. Populations exposed to radon and internal emitters

A standardised protocol has been established for a collaborative case controlled study of lung cancer in areas of Europe which have high levels of radon in homes. A major problem with this study will be the fact that the large majority of lung cancers will occur in smokers and, as the smoking habits vary from country to country, the correction of this confounding factor will be difficult. In order to increase the statistical power of the studies, pooling of European data will be done and later on pooling with US data is envisaged.

The study of thorotrast patients in Germany is almost complete with about 150 patients still alive, but it is important that this study be finished with optimum statistical power. A striking excess of solid cancers, in addition to the liver tumours and leukaemias, is now being observed. The malignant liver tumours are appearing, after a latency period of between 16 and 45 years, about 200 times more frequently than in the controls, however, the association with radiation dose is not clear. The Danish thorotrast study has been re-started using the excellent cancer registry and has revealed a six fold excess of non-squamous cell lung cancer.

The epidemiological study of patients treated with the long-lived ^{226}Ra and the short-lived ^{224}Ra has provided an impressive body of information on the risks of alpha particle emitters. The short-lived ^{224}Ra delivers its alpha radiation to the surface of the bone and osteosarcoma first appeared 3.5 years after the injections, peaked after 8 years and then declined. The data suggest that injections spaced over a longer time span are more effective in inducing cancer than those given in a short time period. A significant increase in chronic myeloid leukaemia has been observed in the low dose group.

Conclusions and Perspectives: Epidemiology

Radiation epidemiology remains an important field of research where a co-ordination of Community and other efforts is required. In recent years standardised protocols and harmonised data collection have been achieved and this has greatly enhanced the quality of the various investigations and their outcome. Epidemiology of radiation exposed populations, especially at low doses, remains a pre-requisite for the determination of low dose radiation risk, but it will be necessary in the future to examine the statistical power of proposed studies carefully in order to optimise the derivable information. It remains an expensive and long-term type of project.

Developments which need to be taken into account in the future concern epidemiology to derive low dose risk. Current risk coefficients are derived essentially from populations acutely exposed to high doses of sparsely ionising radiation, ie. Atom Bomb Survivors and medically treated populations. The exposure of workers and the general population is chronic and protracted over most of a lifetime. There is a need to examine the risks from this prolonged exposure especially to sparsely ionising radiation as there are indications from uranium miner populations exposed to densely ionising radiation from radon that the risk may increase as the rate of exposure decreases.

New molecular biological techniques are revealing the intricate role that genetic background can play in the carcinogenic process. Epidemiological studies will need to take these factors into account in the design and analysis of cohort and case control studies. Studies will also have to examine whether "molecular epidemiology" can improve the ascertainment of cases or possibly be used to unravel the problems of the genetic background and predisposition to cancer.

Theoretical considerations indicate that the magnitude of the radiation risk may be inherently associated with the spontaneous incidence of specific cancers in a population and this has implications for the extrapolation of risk across populations with widely differing levels of spontaneous cancer incidence. This problem will need to be addressed using epidemiological methods.

New studies should concentrate on cohort and case control methods and should avoid the geographical correlations which are sensitive to a variety of confounding factors, are based on "averaging" in both behaviour of the populations and in their exposure and are, in general, unreliable. Sufficient attention will need to be paid to the definition of the correct problem which is to be attacked as well as to the statistical power of the study.

The objectives of research on epidemiology to derive low risk should include comparison of low dose risk after acute and prolonged exposures to both sparsely and densely ionising radiation; investigation of the influence of genetic background on the induction of cancer by radiation; combination of traditional analysis with methodologies arising from biophysical models of radiation oncogenesis; application of new molecular biological techniques in epidemiology.

IV.1.2. Comparative risk assessment

Risk assessments of industrial facilities have become increasingly commonplace over the past decade as it has been recognised that economic as well as safety benefits result from the risk assessment process. Moreover, they have become a regulatory requirement in many areas following several major industrial and transportation accidents. The assessment of the risk of nuclear installations, both in normal operation and in accidents, has been at the forefront of developments in this area. Methodological improvements are, however, no longer confined to the nuclear sphere. Consequently there are benefits to be gained from remaining abreast of developments elsewhere, with a view to achieving cross-fertilisation of ideas and facilitating the transfer of methods, where appropriate, between the various disciplines. These considerations have been the major motivation behind the research carried out in this area. The other major consideration has been to put the risks of radiation exposure into perspective with other carcinogenic and mutagenic agents.

A range of studies have been undertaken aimed at the development of a methodological framework for comparative risk assessment and elucidating some of the key issues through case studies. These have included the management of carcinogenic risks in industry, the management of the transportation of hazardous substances, an analysis of a range of toxic substances; a comparative study of the chemical and radiological hazards to which the population of south-east France was exposed (Greater Rhone Delta) including indoor radon, pollutants released in the use of energy for domestic heating and emissions from household products, etc. One of a number of issues to emerge was that there was wide variation, in both the conventional and nuclear industries, in the implied amounts being spent to avoid the loss of a statistical life by various risk reduction measures; this ranged from about 0.1 to 100 MECU.

The focus for the research since 1990 has been the development of a sound conceptual framework and methodology to assess the environmental impacts of alternative means of energy generation, in particular by the use of coal or nuclear fuels. The basic methodology has been completed but it requires refinement in a number of areas. This methodology is currently being used as the basis for the evaluation of the external costs (ie, those not accounted for explicitly in the economics of energy generation by different means - eg, effluents, waste disposal, accidents, etc.) of generating energy by different means. This is a major joint study being undertaken by the CEC and the US, with the CEC input being coordinated through he JOULE programme. The existence of this methodological framework will facilitate fairer comparisons between the environmental impact of different energy systems; much remains to be done, however, to ensure that the estimation of the environmental and health impacts of conventional pollutants is made on a comparable basis to that for radioactive pollutants where the techniques and data available are at a more advanced stage. Improvements in the modelling of conventional pollutants is important in order to assist in sounder and more optimal allocation of resources to achieve environmental and health improvements.

IV.1.3. Risk from exposure to natural radiation

The term "natural radiation" encompasses what is strictly natural and what is technologically enhanced due to non-nuclear human activities. The later case however is discussed in chapter I.B.

For the former case, attention was paid to the radon issue. In a first period, emphasis was given to the study of parameters and processes influencing the level of exposure to radon in order to increase the understanding of the physical and biological processes and to develop practical and cost effective remedial actions. Some surveys of indoor exposure to radon in the more recent Member States continued to be supported.

Later on, emphasis was given to four topics: (i) Radon sources, modelling of ingress and remedial actions; (ii) Physico-chemical studies and indoor aerosol behaviour (as a base for the evaluation of the health effects); (iii) Retrospective assessment of indoor exposure to radon; (iv) Geological factors influencing the identification of radon hazard areas.

Throughout the programme, intercomparison and intercalibration exercises were regularly organised to ensure the quality of the radon measurements.
The Commission organised at Salzburg, from 22nd to the 28th of September 1991 the fifth Symposium on the Natural Radiation Environment. This was done in cooperation with the Office of Health and Environmental Research of the USDOE, with the collaboration of the Department of Biophysics of the University of Salzburg and with the support of IAEA, Vienna. The meeting was attended by more than 300 participants coming from 38 countries. It included 100 poster presentations and 90 oral presentations including 11 invited papers.

IV.1.3.a. Radon Surveys

It has now been decided to let to the national authorities the responsibility for the execution of national surveys. The results obtained so far permitted that in 1987, an ad-hoc working party of the Group of Experts set up in accordance with Article 31 of the EURATOM Treaty published a report outlining the situation within the Community and that in 1991 an atlas of the natural sources of ionising radiation in Europe was published.

IV.1.3.b. Physico-Chemical Properties of Radon Progeny

Lung modelling requires the knowledge of the regional deposition of the radon decay products in human airways and, consequently, the knowledge of the physico-chemical characteristics of the radon progeny.The deposited fraction of the total amount of the inhaled radon daughters and the deposition site in the bronchial tree depend on many parameters such as the physical and chemical characteristics of the airborne particles carrying the radon decay products, the way of breathing, the breathing rate and the size and form of the airway. Especially the particle size of the aerosol-attached activities and of the "unattached" activities are in all dosimetric

models important parameters for the estimation of the natural human radiation exposure.

Activity size distribution, clustering and attachment processes, plate-out rates, influence of trace-gas impurities, modification of the equilibrium factor and change of the unattached/attached ratio are being evaluated, as a function of all indoor factors under realistic living conditions. Recent findings in this field indicate that measurements of these parameters in the domestic indoor environment are very different from those measured outdoors or especially in the mining environment.

A numerical code recently developed (AERO1A) was used to describe the size distribution of three relevant short-lived decay products of radon (^{218}Po, ^{214}Pb and ^{214}Po). Most of the relevant processes were taken into account, physical (ventilation, attachment, deposition of the attached and unattached fraction and recoil) as well as physico-chemical (clustering, growth and neutralisation of the free radioactive ions). The model, applied to some selected conditions, showed that the active size distributions and the amount of airborne radioactivity are largely affected not only by the aerosol loading of the atmosphere but also by its chemical composition and the dielectric/conductive characteristics of the surfaces in the room.

The progress achieved dealt mainly with the design, construction and calibration of improved size fractionating instruments, of radon chambers and instruments for the determination of the deposited activity in different parts of the human airways. Although the improvement and development of experimental techniques had highest priority which is of absolute need in this field, progress was also achieved in the determination of aerosol size characteristics, activity concentrations of radon-222 and -220 and their short-lived decay products in the domestic environment, the determination of activity deposition in the human lung and controlled chamber studies concerning the plate-out rates of radon progeny.

IV.1.3.c. Effect of the behaviour of radon decay products on the effective dose equivalent

Measurements of the unattached fraction (fp) show that calculations of natural exposure of the public are mostly based on incorrect values for the unattached fraction of short-lived radon decay products. Under normal conditions, the mean fp value of 0,095 is three times greater than that proposed in the literature (fp = 0,03). Measured radon progeny concentrations were fitted to a room model using average deposition rates of the unattached daughters, and the parameters important in dosimetric models were assessed. This enabled the effective dose equivalent to be computed by means of the Jacobi-Eisfeld or the James-Birchall model, and yielded a conversion factor per unit of radon gas concentration of 50 μSv annual effective dose equivalent for 1 $Bq.m^{-3}$ radon concentration. This conversion factor was used in the Commission Recommendation of 21 February 1990 on the protection of the public against indoor exposure to radon (90/143/Euratom, O.J N° L80, p. 26-28) giving for existing buildings a reference level= effective dose equivalent 20 mSv per annum (=400 $Bq.m^{-3}$) and for future constructions a design level= effective dose equivalent 10 mSv per annum (=200 $Bq.m^{-3}$).

IV.1.3.d. Improvement of lung dosimetry and assessment of health effects

Aerosol transport and deposition in the respiratory tract, with special attention paid to the upper airways, was investigated using a hollow anatomical cast and two nasal casts obtained from cadavers, and monodisperse aerosol particles in a range of 6 to 150 nm. Very few particles with diameters greater than 20 nm are deposited in the nasal airways, most entering the lung. Smaller aerosols are deposited in the upper respiratory tract, especially if the particle sizes are smaller than 10 nm. It was suggested that half of the unattached fraction (size from 0,5 to 3 nm) is deposited in the nose.

IV.1.3.e. Radon ingress and development of models

With regard to the radon transport and entry process, a three-dimensional finite difference code (TRISCO) has been applied to model soil gas movement and to predict the performance of radon remedial measures. Calculations with this model can take into account indoor-outdoor pressure differences, joints and cracks in the floor, permeabilities of soil and building materials and the presence of remedial actions. The domain of validity of the model was defined and the main hypothesis (radon entry mainly occurs through pressure-driven air flow, the air flow under the slab is supposed to be laminar and a steady-state condition is adopted) was justified. Because the model allows all the details of a configuration (geometry of the substructure, permeability of the soil,...) to be taken into account in a very simple way, and because of the useful graphical outputs (2 and 3 dimensional) the code appears to be particularly well suited for calculating pressure fields in the soil under and around a structure, thus allowing practical evaluation of the performances of mitigation systems.

IV.1.3.f. Development of effective remedial actions

The effectiveness of dose reduction by treating the indoor air by means of conventional filtration, electro-filtration and electrostatic plate-out was assessed. Simple filtration only gave a modest reduction in exposure. Ventilation can reduce the potential alpha energy concentration and the dose to about 20% of the unventilated level, but may conflict with household comfort and energy budgeting and, if incorrectly applied, may cause an increase in indoor radon level when it depressurises the house. Removal by filtration and electrostatic plate-out is nearly as effective as ventilation. Each of these procedures reduces the dose to about 40-60% of the pre-mitigation level depending on the type of device and the size of the room.

Effectiveness of practical radon remedial measures was studied in 150 homes. The remedial actions adopted were classified according to householders' replies to questionnaires. The study showed that subfloor depressurisation was the most effective and reliable radon reduction technique, generally reducing radon levels by an order of magnitude.In all cases where a large reduction was not achieved, the problem was traced to improper installation or failure of a potential component (especially fanspeed controllers). The next most effective technique was positive

ventilation, if applied in homes with limited natural ventilation. Sealing of timber floors and depressurisation of the space beneath them is no longer advised as it may promote the rotting of floors.

Practical radon remedial actions were also studied for use in schools with high radon levels. Following tests, mechanical ventilation systems producing an overpressure were installed, achieving a substantial radon reduction. In a second school, sealing of soil gas entry routes and improved ventilation under floors were sufficient to reduce radon concentrations to an acceptable level.

IV.1.3.g. Natural radioactivity in the environment

Substantial concentration of radon occurs in some water sources, and these have been used, and are still being used, for health care purposes. In Greece, several dozen radon treatment centres exist with a total of about 1 million visitors per year. The concentration of ^{222}Rn in these Spa waters is among the highest in the world (up to 10^7 Bq m^{-3}). Conservative estimates of annual effective dose equivalents of personnel for current operational practices may be over 100 mSv y^{-1} and typically from 3 to 30 mSv y^{-1}. Conservative estimates for the patients do not exceed 3 mSv.y^{-1}.

IV.1.3.h. Retrospective assessment of indoor exposure to radon

This point is rather innovative and, if the technique is proved to be reliable, could provide important information for epidemiological studies, with a view to decreasing the uncertainties linked to retrospective dosimetrical measurements.

It has recently been shown that $^{210}Pb/^{210}Po$ embedded in glass surfaces can be used as an indicator of long term indoor radon exposure levels. This implies that long term time-integrating radon detectors are possibly present in any house. The experimental results obtained so far are very promising but further investigations are needed to assess the inherent variability of the method. The aim of this project was to investigate the prerequisites for using long-lived radon decay products in dwellings as retrospective risk estimators. The quotients of implanted Po-210 in indoor glasses and radon exposure are scattered about 10^{-3} (Bq.m^{-2}/Bq.y.m^{-3}); however it was concluded that the fact that the true radon exposure value is not known makes it difficult to "calibrate" the glass-polonium system by *in-situ* sampling of glass panes. The influence of all indoors parameters like the influence of electric fields, advectory air-current, etc...has been studied. Results indicate that trapping of alpha recoils by dirt and dust is a minor problem but that advectory current can seriously affected the quotient. A device used to measure the plate-out characteristics of the short-lived radon decay products was developed and improved.

IV.1.3.i. Geological factors influencing the occurrence of radon hazard areas.

The primary aim of the project was to carry out an integrated and multidisciplinary investigation of the geological factors controlling the occurrence of certain high radon exhalation sites in Western Ireland.

Specifically the project set out to: i)determine the geological controls of radon production and migration in karstic limestone terrain; ii)develop a more efficient and effective field sampling methodology for radon detection and test the use of soil-gas helium mapping as an aid in delineating radon migratory routes. This study showed that geological mapping, when supported by combined Rn-He soil gas surveys, can succeed in defining radon availability over broad geographic areas of varied geology and pedology. Further development of such predictive mapping methodologies could assist in focusing the indoor monitory campaigns of EC radiological institutes in a more effective way. They may also be used to categorize areas in terms of Rn potential which are designated for urban development and thereby help to reduce or avoid the cost of later remedial actions. The mapping methodologies employed suggest that for specific house sites the migratory routes for Rn transport are likely to be very localized physical pathways. Site specific measurements of soil Ra-226 activities may fail to show a meaningful correlation with indoor radon levels for a variety of reasons. Also in the United Kingdom, detailed measurements were made of radon in soil gas, gamma ray spectra and uranium and radium levels in soils in two areas. In both areas there were statistically significant correlations between lithology and radon in soil gas, and between radon in soil gas and radon in homes

Conclusions and Perspectives: Risk from exposure to natural radiation

The Programme period under consideration has been characterised by rapid progress in the determination of the parameters responsible for radon exposure and the understanding of the basic mechanisms involved. Among the most important achievements were the definition of a conversion factor of 50 μSv per Bq m^{-3} radon gas, the elaboration of means to determine radon exposure in a reproducible way and the development of cost-effective remedial actions. Indoor radon exposure, being the most important single contributor to the exposure of the population, requires not only regulatory initiatives, the elaboration of building codes etc., but also remains an important challenge for Community research and an area for continuing effective co-operation with the United States and with the Coordinated Research Programme on "Radon in the Human Environment" conducted by IAEA.

At the community research level, emphasis will be put on the development of cost effective remedial actions applicable in all the Member States (different building conceptions), on improvement of the techniques of radon exhalation measurements and on improvement of the estimation of the risk factor due to the inhalation of the radon decay products through a close collaboration between specialists in the radioactive aerosols behaviour, in the lung modelling and in animal experiments. Nevertheless, the nature of the problem is now sufficiently known to expect Member States already take initiatives with a view to mitigation policies adapted to their particular situation. The most immediate task for the Member States is that the public be adequately informed on the radon problem. The Commission of the European Communities has issued a Recommendation which offers detailed guidance for the development of such policies and it is expected that this will contribute to a harmonised approach at Community level.

IV.2. OPTIMISATION AND MANAGEMENT OF RADIATION PROTECTION

IV.2.1. Probabilistic Accident Consequence Assessment

The assessment of the radiological consequences of potential accidents has been an important activity since nuclear energy was first used for commercial purposes. It is an integral part of safety assessments undertaken to ensure that nuclear installations meet the criteria set for them. It also plays a major role in both the development and application of off-site emergency arrangements for protecting the public in the event of an accident.

In order to estimate the radiological consequences of potential accidents, the transfer of released radioactive material through the environment to man by all significant pathways needs to be modelled and, subsequently, the biological effects of any resulting exposure assessed. Among the processes that must be modelled are atmospheric dispersion, behaviour of material deposited on a variety of surfaces, transfer through the terrestrial and aquatic environments to man, the metabolism of radioactive material taken into the body and the biological effects of the exposure of different organs and tissues. A large part of the research undertaken within the Programme as a whole, in particular in the areas of radio-ecology, dosimetry and biological effects, is directly relevant to this task. The quality and extent of knowledge and understanding in these and related areas largely determines the reliability with which accident consequences can be estimated.

Prior to the 1970s, the assessment of the radiological consequences of accidents was largely confined to the estimation of doses to people representative of those who, because of their habits or place of residence, were likely to be typical of those most exposed. Major advances, in the early 1970s, in the techniques used to quantify both the frequency and magnitudes of postulated accidents and the stochastic effects of radiation exposure enabled estimates to be made of the risk from operation of nuclear installations. Risk quantification has since become an important input to the regulatory process, to judgements on risk acceptability, to the identification of safety improvements, and to developments in emergency planning. These changes have major implications for the methods used for accident consequence assessment, in particular for the reliability of the estimates, especially, when they were being used in the contexts of regulation and risk acceptability.

To respond to the developing needs in this area, a major activity was launched within the Programme at the beginning of the 1980s. The activity was entitled MARIA - Methods for Assessing the Radiological Impact of Accidents. The main objectives of this work were to develop a probabilistic accident consequence code that was modular, that incorporated the best features of those models then in use, that was broadly applicable and capable of finding wide usage in the EC, and that could be readily modified to take account of new data and/or model developments. Additional objectives were to quantify the uncertainties in the model predictions and to identify how, if necessary, these might be reduced. A significant programme of experimental work was also undertaken in parallel with the code development in

those areas where improved data were essential to improve the overall reliability of the model predictions. About 20 contractors from 12 institutes were involved in the project. Much of the experimental programme was focused on the deposition and subsequent behaviour of radioactive material in urban areas, in particular on retention of caesium on surfaces, the ratio of doses indoors to those outdoors and to simple remedial measures for dose reduction.

This activity is now largely complete and the code system that has been developed (COSYMA - COde SYstem MAria) has been distributed to more than 30 institutes in the EC and to selected institutes elsewhere. The availability of this code is of considerable benefit to many Member States at a time when increasing attention and importance, within both the regulatory and political processes, are being given to the quantification of risk from major industrial activities. As part of the quality assurance of the code system an intercomparison of the predictions of accident consequence codes is being carried out under the auspices of CEC and the Nuclear Energy Agency and the Organisation for Economical Cooperation and Development (OECD). Some eight codes are participating and the exercise is providing valuable interaction between COSYMA users.

Research and development is continuing in this area, albeit at a reduced level, and two main objectives have determined its direction and content; firstly, to facilitate use of the code by a much larger number of users, thus enhancing the benefits from its development and, secondly, to quantify the uncertainties in its predictions. The former objective is being achieved through the development of a PC (Personal Computer) version of COSYMA, the demand for which is anticipated to be well in excess of one hundred. The PC version is largely "application" oriented and contains a number of simplifications compared with the main frame version which was research focused; it will be available by mid 1993.

The increasing use of quantitative safety objectives in the design, operation and regulation of nuclear installations has necessitated reliable estimates to be made of the uncertainty in probabilistic accident consequence codes. This need has been recognised both within the CEC and the US Nuclear Regulatory Commission and the detailed planning of a major joint project on this topic is currently under way; the project will be implemented through 1993-94. Estimates have already been made of the magnitude of the uncertainty in consequence code predictions, but they suffer from two potential criticisms. Firstly, much judgement is inevitably involved in the selection of distributions of parameter uncertainty (which ultimately determine the overall level of uncertainty in the consequence predictions) and the basis for this has rarely been fully documented; secondly, the estimates have generally been made by the code developers and it is debatable whether they are the most appropriate group to have made these judgements.

To overcome some of these potential criticisms, formal expert judgement elicitation will be used in the joint CEC/USNRC project to determine uncertainties in parameter values. These techniques were used extensively in a recent USNRC study (NUREG-1150) of the risks of reactor operation but their application was limited to the estimation of uncertainties in the probabilities of accidental releases and their

magnitudes. A pilot study, using similar techniques, has also been carried out within the CEC; it was limited to one module of the COSYMA code, that concerned with atmospheric dispersion and deposition.

Several benefits will ensue from undertaking this project jointly with the USNRC, in particular it will allow a more effective use of resources than two independent studies, it will provide access to a greater pool of experts, and it will give the outcome of the study greater credibility both technically and politically. Once complete the results of the study will provide a useful input with respect to judgements on the extent to which quantitative safety objectives are being met.

The VAMP (Validation of Model Predictions) project being undertaken jointly by the IAEA and CEC will also contribute to a better understanding of the origins and magnitude of environmental modelling uncertainties. The wealth of data obtained following the Chernobyl accident are, inter alia, being used for this purpose.

IV.2.2. Decision support systems for off-site management

Procedures for the rapid assessment of the radiological consequences of an accidental release have been an important feature of emergency planning since the introduction of nuclear energy for electricity production. There have, however, been major improvements in the ability to make such assessments in the intervening period, in particular during the past decade. Several factors have contributed to these improvements, not least the very substantial increases in available computing power, better meteorological forecasting and predictions of dispersion in the atmosphere and improvements in the monitoring of radioactive material in the environment. The two accidents at Three Mile Island and Chernobyl were also influential in the sense that they resulted in increased resources being allocated to this area in many countries.

This topic has featured prominently in the Programme throughout the past decade with a major increase in the resources devoted to it following the Chernobyl accident. Within the framework of the post-Chernobyl research programme (see Section IV.3.) four institutes collaborated on the development of some of the basic modules of a real-time system for use in emergencies (DART - Dose Assessment in Real Time). Three of the modules are concerned with the prediction of atmospheric dispersion over short, medium and long distances; the fourth is concerned with the assessment of the impact of a release based on the predictions of these dispersion models and/or environmental monitoring information. Procedures for the feedback of monitoring data are included to update the predictions of the dispersion models. A software package containing the modules has been prepared and made available to others working in this area.

Further increases in the resources allocated to this area occurred in both the 1990/91 and 1991/92 programmes. Some 12 institutes were involved in the 1990/91 programme and this has now increased to 16. The work being carried out by the respective contractors is closely integrated and effective links have been established with a number of institutes in the former Soviet Union and in the US. The main

objective of this project is to develop a system which is able to support decision makers in the event of any future nuclear accident in determining how best to mitigate its consequences. The system will be capable of broad application both in the EC and elsewhere. A number of systems of this type already exist but, in general, their scope and applicability is greatly constrained in comparison with the system under development. By bringing together, within the project, the expertise from a large number of institutes in the EC and elsewhere, advantage is being taken immediately of what already exists and the limited resources available can be directed to those areas where further developments are most needed. In addition to its main role of providing decision support in an emergency, the system will be developed in such a way that it can be used extensively in a training mode and in the exercising of emergency arrangements.

A first prototype version of the system was prepared in the autumn of 1992 and was demonstrated at an International Workshop on Real Time Systems for Off-site Emergency Management. A second prototype will be completed by mid-1995 prior to the development of a fully operational system which is intended for practical application in the second half of the 1990s. The system will be useful to a wide range of organisations in the EC and elsewhere with an interest in or responsibility for off-site emergency arrangements. It will be at the forefront of developments in this area internationally and will have the capacity of providing those with responsibility for introducing off-site countermeasures with the best information possible to aid well-founded decisions.

The first prototype of the system will be provided in 1993 to institutes in the Ukraine and Russia and used as a platform to integrate the research and development activities of these groups within the overall project.

IV.2.3. Optimisation of Protection (ALARA)

The requirement to optimise protection or to reduce doses to as low as reasonably achievable (ALARA), social and economic factors taken into account, continues to have a central role in the new recommendations of ICRP. Much progress has been made in this area since this requirement was given particular prominence in ICRP's recommendations in the early 1970s at both the conceptual and practical level; research conducted within the framework of the Commission's Radiation Protection Research Programme has contributed significantly to these developments.

Research within the Radiation Protection Programme has focused on the theoretical basis and the practical implication of the ALARA requirement and, in particular, on methods to assist in this process (eg, cost-benefit analysis, multi-attribute techniques, etc). This work continued through much of the 1980s, and has culminated in the development of a procedures guide and software package to aid users in carrying out analyses to demonstrate that doses have been reduced to ALARA. Training courses are now being held on a regular basis to communicate the guidance and techniques developed to those with a professional responsibility in this area. The continuing high demand for places on this course is indicative of the importance attached to this issue both by industry and regulatory authorities.

Moreover, the increasing realisation that the formal inclusion of ALARA considerations, generally into design and work planning, results in better protection at a lower overall cost (consequent upon the attention to detail and the adoption of more structured and disciplined approaches) is leading to increasing demands by industry for those skilled in the application of these techniques - a need which can only be satisfied by further training.

The conceptual basis and practical implementation of ALARA in normal operation of nuclear installations (eg, effluent discharges and occupational exposure) is now relatively mature; consequently, the emphasis in these areas has shifted from development of techniques to their application in new areas and to training. Much, however, remains to be done regarding the application of optimisation to probabilistic situations and to the establishment of intervention levels following a nuclear accident. These two aspects are receiving attention in the ongoing research programme and will receive increasing emphasis in the future.

IV.2.3.a. Intervention

Notwithstanding the broad international consensus that existed on the fundamental principles underlying intervention, significant differences arose in the intervention levels adopted in various countries following the Chernobyl accident. Consequent upon these differences, various attempts have been made to clarify these principles but without any major change in their substance. It has become evident that it is not the principles, *per se*, that are the problem but their application and it is in this area that more research and development is needed. The more traditional and well established techniques of cost-benefit analysis still have a useful role to play in this area but this is mainly to provide perspective; the limitations of the techniques become apparent when socio-political factors become important in the decision process. Alternative techniques are needed to aid decisions in this area and within the RADEAID project (carried out within the post-Chernobyl Programme - see Sect. IV.3) it was judged that, from among the techniques available, multi-attribute value analysis offered the greatest potential.

Within this project a software package was developed which can be applied with relative ease to aid decisions on complex multi-attribute problems. The package is currently only available in a demonstration version and the final version will be available in 1993. The techniques and software package are applicable generally and not only to the problem of intervention levels. Supporting data bases are being prepared on the radiological and economic consequences of a spectrum of hypothetical accidents subject to a range of assumptions on the intervention levels of dose at which countermeasures will be introduced. These data bases, coupled with the decision analysis package, can be used to evaluate a range of intervention strategies subject to various value judgements on the less quantitative inputs to decisions in this area. This will, in due course, lead to better and clearer understanding of the issues relevant to decisions on intervention and of their relative importance.

Decision conferencing has also proved a powerful and effective technique to aid the resolution of complex problems. These techniques were used with much success in the USSR as part of the Commission's contribution to an international evaluation of the measures taken in the USSR to protect those living in regions contaminated as a result of the Chernobyl accident. A decision conference typically takes place over two days and is attended by those who share a particular problem and have commitment to its resolution. It combines the features of group dynamics, decision analytic techniques (such as multi attribute value analysis) and information technology and is run by an independent facilitator who has expertise in each of these areas. Efforts will be made over the next two years, through training and information meetings to bring these techniques to the attention of a wider audience and encourage their use within the radiation protection and nuclear safety communities.

IV.2.3.b. Potential exposures

Optimisation of protection for potential exposures presents a number of conceptual and practical challenges and is an area where little progress or consensus has emerged over the past decade; current international guidance on this remains cursory. The problems to be addressed are now well recognised and will be the focus of increased research effort in the future. The objectives of the research will be to establish a common framework for optimisation in this area that has a sound conceptual basis and is capable of finding broad acceptance. The subject is of direct interest and importance to both the nuclear safety and radiological protection communities and effective interfaces will need to be established to ensure the success of future research in this area; the difficulties of making substantive progress in this complex area are not, however, to be underestimated.

IV.3. POST CHERNOBYL ACTIONS

Following the Chernobyl accident, a number of additional research requirements were identified resulting in the addition of ten projects to the Programme. Two of these projects were directly relevant to this sector of the Programme

Action II. IMPROVEMENT OF RELIABLE LONG DISTANCE ATMOSPHERIC TRANSFER MODELS

Models of long-range pollutant transport have a variety of uses in the context of accidental releases of radioactive material. In the early stages after or during an incident, they can assist in providing an indication of when and where contamination might be expected to appear and what its severity would be for a postulated or known release. As measurements of environmental contamination become available, models can play a further role: if the characteristics of the release, particularly the amounts of various radionuclides, are not known, they could be used to 'work back' from measurements to properties of the release. They also provide a tool for an intelligent interpolation or extrapolation from the measurements to estimates of contamination levels in areas where no data are available.

The use and importance of long range transport models in these contexts was exemplified during and after the Chernobyl accident. Most of the models used existed long before the accident and had been developed with specific uses in mind, having their assumptions and simplifications tuned to those particular applications. Wide variation exists in the complexity of the models used and in the demands they make on meteorological data and on computational resources. Few of them had been developed or optimised specifically to provide, following an accident, inputs in real time to emergency response systems.

The focus of much of the research carried out within this action was to evaluate the merits and disadvantages of alternative modelling approaches for the above purposes, to determine the magnitude of any uncertainties or biases introduced by modelling simplifications, and to identify which approaches had the most potential for application to these types of problem. The appropriate level of model complexity and model validation were two of the key issues addressed. Significant advantages clearly are to be gained in reducing the model complexity to a minimum compatible with the intended application, in particular because of its implications for computation time.

An in depth investigation was carried out of the uncertainties and biases introduced into the predictions of long range transport models consequent upon different modelling assumptions and approaches. Particular consideration was given to the extent to which the effects of major orographical features need to be explicitly modelled. The use of these models, in conjunction with measured levels of environmental contamination, was also analyzed as a means of estimating the magnitude of material released in an accident and for improving and updating the model predictions; further research is, however, required on this topic to make best use of the available information and to improve the quality of the predictions. These investigations, overall, have succeeded in providing a valuable framework for making decisions on the type and nature of modelling approaches and assumptions that can be accommodated, commensurate with the reliability demanded of the application. This information will be of considerable value in optimising the design of off-site emergency response systems, especially for application at long distances from a release.

Validation of long range transport models with controlled-release experiments are costly and present formidable logistical problems and, consequently, few have been undertaken. Not surprisingly, therefore, the radiological data collected from Chernobyl are viewed as a potentially valuable resource for model-evaluations. However, Chernobyl was not a controlled experiment and there will, inevitably, be limitations in its use for such purposes, not least resulting from a lack of homogeneity in how the various data were measured and reported. In order to benefit most from the use of these data, they need thorough collation and examination. A sub-set of the data have, therefore, been subjected to critical analysis and methods, which are generically applicable, developed to identify erroneous or suspicious data in the data base. Empirical descriptions were also made of the data and can be used to make predictions of contamination levels at locations where no measurements exist. The application of these methods more widely offers the potential to create an improved

and more valid data base. The techniques developed could be applied readily to data collected in any future accident and thus provide some measure of quality assurance.

Action III. RADIOLOGICAL ASPECTS OF NUCLEAR ACCIDENT SCENARIOS

Following the Chernobyl accident, it was recognised that improvements were needed in the methods used to predict, in real time, the environmental impact of an accidental release of radioactive material. These predictions are an important input to decisions on the introduction of countermeasures following an accident and, consequently, their quality has a direct bearing on that of the decisions taken. Many of the countermeasures that can be taken to avoid radiation exposures are costly, may be disruptive to life and cause anxiety, and, moreover, may themselves introduce additional risks. Decisions on the introduction of countermeasures must, therefore, be taken carefully and based on the most reliable information available at the time. The research undertaken in this action was directed, firstly, towards the development of improved and more broadly applicable methods for assessing doses in real time during an accident; and, secondly, towards the development of techniques that could be used to aid decision makers in making difficult choices between alternative courses of action, each of which may have competing merits and disadvantages.

A. Dose assessment in real time

Prior to the Chernobyl accident, emergency planning had been concentrated on areas immediately surrounding nuclear installations where people would be most at risk were an accident to occur. The extent and nature of the planning reflected judgements on the probability with which an accident may occur and its potential magnitude. The widespread dispersion of radioactive material following the Chernobyl accident drew attention to the desirability of having arrangements that would in future be capable of dealing with accidents having an impact far from the installation itself. An essential step in the formulation of such arrangements is the prediction of the impact of a release over large distances and the research undertaken was directed towards these ends.

A suite of models has been developed which forms the key elements of a system that can be used, in real time, to predict the potential consequences of an actual or threatened release of radioactive material. The suite of models comprises three main components and is concerned, respectively, with the prediction of the dispersion in the atmosphere of released material, the transfer of material deposited onto the ground through the terrestrial environment to man and the estimation of the magnitude of the release from measurements of radioactive material in the environment.

Three models have been developed to predict atmospheric dispersion for use over different ranges of distance from the source of the release, in particular local to the source of the release (out to a few tens of km), over mesoscale distances (out to a few hundred km) and on a continental scale (out to several thousand km). The models differ in the complexity with which they treat dispersion processes. In each

case they represent a compromise between making the most reliable estimates possible within the available time. Close to the release predictions need to be made very quickly to enable a rapid response and the modelling approach must, in general, be much simpler than at greater distances. More complex meteorological phenomena need to be modelled if reliable predictions are to be made of dispersion over large distances; in such cases, however, much more time is available for the calculations before decisions need to be made on the introduction of countermeasures. The inclusion of separate models also provides the user with the flexibility of choosing the model or models most suited to his interests. Appropriate interfaces have been developed between the models.

As an accident progresses there is a continuing need to update the predictions of the dispersion models in light of any measurements made of radioactive material in the environment. Two models have been developed for this purpose and are applicable generally in one case and limited to short distances in the other. The performance of these models has been tested for a limited range of conditions by comparison with experimental data.

Decisions on the introduction of countermeasures are strongly influenced by the potential levels of dose predicted. A further model has, therefore, been developed to calculate exposure by each of the important exposure pathways (external irradiation from and inhalation of the plume, external irradiation from material deposited on the ground, and ingestion of contaminated food) based on measured concentrations of radioactive material in the environment or on the predicted levels in the atmosphere and deposited on the ground. Account is taken of people's habits in estimating doses and of the season of the year and a variety of other agricultural factors; these can have a profound influence on the magnitude of the potential dose from food consumption and, consequently, on the scale and extent of any food restrictions that may need to be imposed.

The research has been successful in the development of a suite of models that can form the basis of a computer system for use in aiding decisions on off-site emergency response in the event of an accident, irrespective of the distance from the release location. The models represent the state of the art of development in their respective areas and contain a number of improvements over what was previously available. A computer software package has been prepared containing each of the models. This package is being made generally available and will be of considerable assistance to those with an interest in this area. The benefits of this research will, however, only be fully realised when the models are incorporated into operational systems for use in off-site emergency management. Ongoing research within the Programme is now being directed towards this end, in particular towards the development of a comprehensive and versatile decision support system within which the models developed will be incorporated.

B. Decision aiding techniques

Decisions on the introduction of countermeasures are often complex in that they generally require a balance to be made between several competing objectives.

International guidance has been developed to assist in this area but it is often generic in nature and needs to be supplemented before it can be applied effectively to particular situations. This is inevitable if optimum decisions on countermeasures are to be taken; there may, for example, be wide differences in the nature of and the circumstances in which an accident may occur, and also in the available resources for and the practicability of particular countermeasures. Emergency planning is, therefore, often based on specific quantitative guidance with an allowance for flexibility of response to accommodate the situation actually encountered.

The basic principles which underlie decisions on countermeasures are that their introduction should be of net benefit to those affected (ie, their introduction should do more good than harm) and, to the extent practicable, this benefit should be maximised. In order to satisfy these principles it is necessary to evaluate all the beneficial and detrimental consequences of introducing countermeasures. The main beneficial effect will be the radiation exposures averted whereas the detrimental effects may take several forms including cost, inconvenience and disruption of lifestyle, any additional risk associated with the countermeasure itself, anxiety, etc. The balancing of these and other disparate effects is further complicated by social considerations, in particular the question of equity given that the benefits and costs are not necessarily borne by the same people. The decision problem is thus complex but is a common feature of decision making in the social sphere and a variety of formal decision aiding techniques are available to assist in the resolution of such problems.

The merits of different decision aids have been investigated and, for the decision problem of interest, it was concluded that the technique of multi-attribute value or utility analysis had the greatest potential. Based on this technique a decision aiding system, RADE-AID, has been developed which enables the user to compare and rank different countermeasures strategies taking into account both quantifiable factors and those of a more qualitative nature such as social and political considerations, subject to the assignment of relative weights by the decision maker to the various factors. The user can interact directly with the system and explore the implications of assigning different weights or importance to the various factors which may influence the decision. The system is not, however, a replacement for the decision maker but rather a decision aid which enables a broad range of alternatives to be explored quickly and, more importantly, in a consistent, structured and transparent manner.

A prototype version of the system has been completed and has been made available to other institutes actively involved in research in this area. Within the current Programme the system is being further refined and developed for possible use as a formal aid in a re-appraisal of criteria for the introduction and later withdrawal of a variety of countermeasures (eg, relocation). The system also has considerable potential for application in real time off-site emergency response systems and its use in this context is being evaluated. A further important use is in training exercises for those responsible for making decisions in an actual emergency and this will be followed up in due course. Further benefits are also expected to ensue from this

work once the system is further refined, in particular its application as a decision aid to a number of more complex radiological protection problems, for example, judgements on when accident risks have been reduced to as low as reasonably achievable.

Action V. UNDERLYING DATA FOR DERIVED EMERGENCY REFERENCE LEVELS

After an accidental release of radioactive material into the atmosphere leading to significant off-site contamination, radiation exposure of the population can be reduced by means of various countermeasures such as sheltering, issuing of stable iodine tablets, restrictions on agricultural production, temporary evacuation, relocation of the population. Often, restrictions in the consumption of contaminated foodstuffs can be an appropriate countermeasure and this was extensively used after the accident.

Prior to the Chernobyl accident, the Commission had suggested a high and a low Emergency Reference Level for different countermeasures which were to be applied according to the specific situation: a higher level above which the countermeasure should generally be implemented and a lower level of exposure below which the countermeasure is unlikely to be justified. In order to allow a general application, the Commission, on the advice from the Article 31 Group of Experts, took only the lower Emergency Reference Level as the basis for deriving "maximum permitted levels of radioactive contamination of foodstuffs and feedingstuffs".

The Article 31 Group of Experts derived these values by elaborating a methodology based on several assumptions which were considered conservative. Nevertheless, the need was felt to verify these assumptions by checking and developing the underlying food chain and dosimetric models and by verifying information of food consumption habits.

The assumption that only 10% of food is contaminated at maximum levels was verified by compiling a huge data set on food consumption. All Member States except Portugal and Denmark were classified into 3 groups with fairly homogeneous diets. When comparing the consumption rates on the "average EC citizen" with those adopted by the Expert Group, the data for cereals, dairy products and meat agreed rather well, whereas some discrepancies were observed for vegetables and fruits. Food consumption was also evaluated for different subgroups of the population. As expected, diet varies markedly with age from the infant, the 1-year-old up to the 18-year-old, with only minor changes at later ages. Within a Member State, regional consumption of certain classes of food may vary from 70% to 130% of the national average. People in urban areas consume less contaminated food - 70% to 100% of the national average but have a significantly higher fruit consumption - whereas people in rural areas consume from 100% to 140% of the average. Where self-sufficiency in food production is high - this is particularly true in the southern part of the EC - local contamination may cause relatively high exposures. The assessment of food distribution in and outside the EC showed that, on average, 84% of food is provided by national production, 13% is obtained from

intra-Community trade; non-EC countries contribute only 3%. Obviously, these values vary widely, dependent on the type of food; highly urbanized and industrialized regions obtain, in general, more food from outside the country.

Existing dynamic models for the transfer of radioactivity through the terrestrial food chain were improved and used for verifying the assumptions made for maximum permitted contamination levels. Two models of differing complexity were compared: FARMLAND (NRPB, UK) and ECOSYS (GSF, D). The simpler FARMLAND model is more suited to be used with default values whereas the more complex ECOSYS model is more appropriate for evaluating more site-specific situations. Using the "default food chain model" and dividing the EC territory into four regions taking into account the different climates and farming practices as well as possible deposition pattern from an accident, the level of contamination of major agricultural products was computed. Values for the dose-per-unit intake were also recalculated for the major radionuclides and for different age groups.

On this basis and using the food consumption patterns established, it was possible to calculate different illustrative patterns of individual doses from ingestion showing the possible variation of individual doses between Member States and to identify those foods that would contribute most to the dose. It appeared that, in general, age has only a small influence on dose and that regional agricultural practices need not be taken into account, except for the Mediterranean countries; however, the season during which the release occurs greatly affects the exposure pattern, with lower values in winter compared to spring and summer.

Based on generally accepted radiation protection concepts and the ALARA principle (As Low As Reasonably Achievable) a methodology for deriving intervention levels for foodstuffs assuming several scenarios could be developed for which the efficiency of countermeasures (doses saved) was assessed. All this information is now being made available in a readily interpretable way to decision-makers. It is hoped that this will contribute to more transparent and better harmonized emergency management.

IV.4. SUPPORT TO INTERNATIONAL ORGANISATIONS - International Commission on Radiological Protection (ICRP)

The radiation protection standards recommended by the ICRP have formed the basis of most radiation protection guidelines and regulations that have been issued by national authorities and international organisations. They underpin the Basic Safety Standards adopted within the EC for the health protection of the general public and workers against the dangers of ionising radiation. The work of ICRP has also contributed effectively to international harmonisation of protection standards in this field. Support has been provided to assist the work of the Main Commission of ICRP and to four Standing Committees and associated Task Groups. The period covered by the 1985-89 and 1990-91 Research Programmes has been one of intensive activity by ICRP leading up to the issue of its new recommendations in ICRP Publication 60 in 1991 together with other supporting or associated reports of its Committees.

IV.C. CONCLUSIONS AND PERSPECTIVES

The progress made in several areas of risk assessment, risk management and optimisation of protection has been commendable and has broadly satisfied the objectives of the programme. The development and distribution of the COSYMA accident consequence code system to several tens of institutes in the EC and elsewhere has been a major achievement; it is of considerable benefit to the users and will assist better and more harmonised estimates of risk in future. The current development of a PC version of the code will enable the benefits of this development to be spread even more widely. The widespread use of this system will necessitate continuing support of this activity to ensure the system remains "state of the art", to incorporate new model developments or scientific knowledge when there is a demonstrable need, and to better quantify the uncertainties associated with the predictions of such codes; the latter is necessary for effective use of the results in a decision making context.

The conceptual and methodological basis of optimisation of "normal" operations is now well established and broadly accepted and is being widely disseminated through training courses for which demand is high. There remain a number of major problems to be addressed with regard to the application of "optimisation" to potential exposure situations (eg, potential accidents). The key issues in this area have largely been identified but much remains to be done to achieve their resolution.

A methodological framework for comparative risk assessment has been established and is finding use in a major international project. Improvements are still needed in some aspects of this framework, in particular to ensure that risks from different sources and of different kinds are evaluated on an equitable basis.

Increasing resources have been directed through the periods of the two Programmes to the development of decision support systems for off-site emergency management. The major achievement here has been in bringing together a large number of contractors to work on the development of a common system - thus taking greatest advantage of existing developments and thus being able to allocate limited resources more effectively to those areas where further research or improvements were needed. A first demonstration version of the system has been produced and this provides a sound basis for the subsequent development of a fully operational system.

Limited progress has been made in the areas of risk perception and communication, topics which are increasingly being recognised as important in gaining public acceptance for the introduction of new technological practices or policies; these aspects are often as important as, if not more important than, technical considerations in decision making in these areas.

Against this background emphasis should be placed in the following areas in the forthcoming Programme.

Risk assessment

Comprehensive methodologies have been developed to assess the health and environmental impact of discharges of radioactive materials to the environment and of potential accidents at nuclear installations. The best available models developed at a national level have been incorporated into these methodologies which are finding extensive use in many Member States and elsewhere; moreover the use of common assessment methods facilitates the harmonisation of standards and is likely to encourage greater uniformity in resource allocation to health and environmental risk reduction.

The future programme in this area should have three main elements:

1. To maintain, improve and update the methodologies in light of new scientific developments and changing regulatory requirements and make them generally available to Member States and to countries in Central and Eastern Europe;

2. To assess the uncertainties associated with the predictions of the models with two main objectives: firstly, to aid better informed decisions on risk management and, secondly, to provide a major input to the setting of future priorities for research in the health and environment areas;

3. To promote the development of more common and equitable methodologies and approaches for the assessment of the health and environmental impact of radioactive and conventional pollutants.

Risk Management and Optimisation

Optimisation of radiation protection is the cornerstone of radiation protection policy and regulation. The application of optimisation to public and occupational exposures occurring during the normal operation of facilities is now relatively mature, but major problems remain with its application to potential exposures and to exposures which may occur far in the future consequent upon present practices.

The future programme in this area should have two main elements:

1. The development of conceptual and methodological frameworks for the optimisation of potential exposures, and for determining intervention following an accident, that are capable of finding broad acceptance and use within the Community, with particular attention being given to the issues of equity and risk aversion to events with large consequences;

2. The development of practicable techniques and associated software to aid decisions on optimisation of more complex problems, such as those encountered with potential exposures.

The establishment of this framework and these techniques will contribute to a more considered and uniform allocation of resources to improvements in safety and environmental protection, both within and between Member States; in addition it will bring added transparency to the allocation of resources in these areas which is increasingly been recognised as an essential component in gaining public acceptability.

Decision support systems for off-site emergency management (RODOS)

A first prototype version of the RODOS system was developed at the end of 1992 and is being installed in several institutes in the EC and Eastern Europe to facilitate its further development. A second prototype will be completed in mid-1995 prior to the development of a fully operational system which is intended for practical application in the second half of the 1990s. Resources in the future programme should be directed to developments essential to the completion of the operational system.

The system once complete, will be useful to a wide range of organisations in the EC and elsewhere with an interest in or responsibility for off-site emergency arrangements. It will be at the forefront of developments in this area internationally and will have the capacity of providing those with responsibility for introducing off-site countermeasures with the best information possible to aid well-founded decisions.

Risk perception and communication

Much research has been undertaken on risk perception and communication in the past five years but much remains to be done to take practical benefit from within the radiation protection community. The focus for future research within the Programme in this area should be:

1. To improve understanding of risk perception with respect to radiation detriment, in particular to assess the response of workers and the public to advice and information on radiation protection for both normal situations and accidents;
2. To develop measures to assess the efficacy of radiation protection advice;
3. To develop guidance on how best to cope with the problems of risk attenuation and amplification;
4. To develop, through a network in the EC, strategies for improved radiation risk communication.

V. OPTIMISATION OF RADIATION PROTECTION IN MEDICINE

V.A. INTRODUCTION

V.B. SCIENTIFIC ACHIEVEMENTS

V.B.I. Methods and Models for Dose Calculations and Measurements

V.B.2. Assessment of Risk Related to Organ and Tissue Doses from Conventional and Special Radiological Examinations

V.B.3. Determination of Dose Increasing and Dose Reducing Factors

V.B.4. Evaluation of Radiological Procedures

V.B.5. Establishment of Quality Criteria of Radiographic Techniques, Radiographic Image and Patient Exposure

- V.B.5.1. Quality criteria for adult radiology
- V.B.5.2. Quality criteria for paediatric radiology

V.B.6. Knowledge Based Systems

V.B.7. Cooperative Efforts

V.C. CONCLUSIONS AND PERSPECTIVES

V. OPTIMISATION OF RADIATION PROTECTION IN MEDICINE

V.A. INTRODUCTION

Medical techniques using ionising radiation are widely employed and are essential for good health care. Nearly every inhabitant in the European Community is examined once a year by X-rays or nuclear medicine procedures. New technical developments and the use of radiological procedures for new interventional techniques are still increasing these numbers. The statistical situation in diagnostic radiology in the EC is shown in Table 1.

TABLE 1

SITUATIONS IN DIAGNOSTIC RADIOLOGY IN THE EUROPEAN COMMUNITY
- 320 million inhabitants; - 200 million radiological examinations per year; - 500 million radiographic films per year: 300 to 1500 μSv contribution to the exposure of each person of the general public per year in the various Member States; 500 μSv average value for the European Community

In several Member States, mass screening programmes for the detection of breast cancer by mammography have been introduced, which means that a large number of asymptomatic women are examined by X-rays. Special attention must be given to the doses delivered during the examination and to the possible risk of inducing cancer.

During the 1985-89 and 1990-1992 periods of the Radiation Protection Research and Training Programme, about 10% of the budget was used for research on optimising the radiation protection of the patient in diagnostic radiology. Multi-national co-operation groups were established and concentrated, and continue to do so, on the following main tasks of Community effort:

- putting emphasis on research which produced the prerequisites for optimum diagnostic efficiency at reasonable doses to the patient and staff and at reasonable costs;

- contributing to the implementation of the EC Directive laying down basic measures for the radiation protection of persons undergoing medical examination or treatment (EURATOM 84/466);

- evaluating data and supporting a more global use of the research results in day-to-day routine work of radiological departments and in training;

- stimulating, facilitating and standardising surveys on a national basis;

- co-ordinating research work.

During the 1985-1989 period, a significantly greater cohesion among the contractors was achieved and this facilitated the creation of the co-operative groups for the 1990-1992 period. The research action benefited from the closer co-operation and the improved distribution of tasks.

The recommendation of the external evaluation panel required that: "dose reduction must remain a high priority and newer methods of reducing dose and alternative imaging and other procedures must constantly be sought. It is noted that dental radiology **may** contribute to the induction of tumours (eg of the parotid gland) in the dental exposure region itself".

V.B. SCIENTIFIC ACHIEVEMENTS

The highlights of recent achievements reflect the efforts that have been made in response to these recommendations. The research work concentrated on Computed Tomography (CT), mammography and paediatric radiology. Work in conventional radiology has reached a state where emphasis should be put on transmitting the results to day-to-day practice and research on digital and interventional radiology is still in the initial phase.

V.B.1. Methods and models for dose calculations and measurements

The projects dealing with dose assessment pursued four main objectives: to deal with the radiation qualities needed for diagnostic purposes, to determine the energy distribution in the organs and tissues; to measure dose variations due to changing equipment parameters and to define reference doses to the patient under realistic irradiation conditions.

The new recommendations of ICRP 60 suggest the introduction of the concept of dose constraints also in the medical field, so that dose calculations and measurements should equally serve to establish reference dose values as a criterion of good radiological practice.

Computed Tomography

Considerable progress has been achieved in computational dosimetry using Monte Carlo techniques to track the passage of X-ray photons through geometric phantoms representing the patient. CT examinations have been simulated on adult phantoms and produced catalogues of data which enabled organ doses to be estimated from simple dose measurements on the CT scanner. Extensive data bases enabling organ doses to be calculated for any type of CT examination on a wide range of scanners

have been supplied to interested EC contractors. A common approach to CT dosimetry is now possible throughout Europe yielding the organ doses of interest in radiation protection in a relatively easy manner. Effective doses of CT examinations may exceed 20 mSv and CT is contributing as much as 20% of the collective dose from all diagnostic radiology in some Member States (see item V.B.4). A new generation of more realistic mathematical phantoms has been developed, based on CT image data from real patients. They contain high numbers of organ specific volume elements, called voxels. By scaling up or down the size of the voxels, the influence of patient size on organ doses for a constant exit dose during typical radiographic exposures has been studied. The results are valuable for assessing the impact of different radiographic techniques and patient size on doses delivered during eg also in paediatric radiology.

Interventional Radiology

Special attention was given to the measurement of doses to the medical staff involved in interventional radiology, for which improved monitoring arrangements are requested. In angioplastic interventions, the highest dose to the examiner is measured at the forehead. The impact of the various technical and personal parameters on dose to the patient and the medical staff has to be studied.

Mammography

Measured and calculated depth-dose distributions in a perspex breast phantom have been compared. For the ionisation chamber measurements, a displacement correction factor has been derived. Agreement between measured and calculated depth-doses appeared to depend critically on the spectral data used in the calculations and whether they were matched to measured half value layers (HVLs) or depth-doses. The relationship between image quality and dose for various technical conditions has been studied and the relative effectiveness of some technical factors has been seen to vary markedly with breast thickness. This is essential for any risk considerations (see item V.B.2).

Therapy and Nuclear Medicine

Doses from radiotherapy or nuclear medicine to organs outside the target region were assessed and it was found that breasts in women can receive significant absorbed doses of 0.16-0.34 mGy during radiotherapy of other organs whereas the breast dose from nuclear medicine procedures is insignificant.

Nuclear medicine procedures contribute less than 10% to the overall population exposure, even if rather higher doses might be applied to the individual. Application in paediatrics, however, is of special interest because of the longer life expectancy and higher reproductive potential. These projects dealt with the establishment of biokinetic data of some new radiopharmaceuticals of the TC-99m series and the use of these data for organ dose estimates.

V.B.2. Assessment of risk related to organ and tissue doses from conventional and special radiological examinations

No general agreement yet exists concerning the quantities relevant for risk assessment in diagnostic radiology. An approach was developed to assess the factors for somatic and genetic risks from diagnostic examinations and to compare them with the risk factors generally accepted in radiation protection. The extra risk for induction of breast cancer in women aged between 35 and 75, screened annually by mammography under optimum conditions, was calculated to be about 1% of the natural incidence.

Mammography

A comprehensive review of the scientific literature covering the field of risk-benefits in breast screening programmes employing mammography has shown that virtually all studies suffer from two main limitations: they nearly all employ average breast sizes and compositions in the assessment of dose to the breast and, therefore, risk; assessment of doses received during examinations does not tend to employ measurements during actual examinations.

It was concluded that existing quality control initiatives in mammographic breast screening programmes which employ standard phantoms to assess breast dose do not appear to fulfil the radiation protection requirements of the Basic Safety Standards (EURATOM 80/838) and the Patient Directive (EURATOM 84/466). The need was stressed for taking into account more realistic variations in breast thickness, and adaptation of risk assessments to the new models recommended by ICRP 60.

Paediatric Radiology

The suspected higher sensitivity of paediatric patients to deleterious health effects from radiation exposure is likely to be affected by the recent revisions in the health effects models used to predict radiation detriment. These models have been analyzed and a database has been developed which enables health detriment from radiation exposures to be evaluated as a function of the age and sex distribution of the exposed population. Preliminary results indicate that for typical X-ray examinations, the health detriment per unit dose for paediatric patients will be on average nearly twice that for the general population whereas for geriatric patients it will be less than one fifth.

V.B.3. Determination of dose increasing and dose reducing factors

Research efforts on reduction of patient exposure are not replaced by the efforts on the side of the manufacturers of radiological equipment. They optimise engineering design in answer to user's requirements, but radiation protection requirements are not sufficiently taken up.

Among the factors and practices that influence dose to patients, the skill of the operator, the age of the equipment, the establishment of standards as well as the

frequency of standardised performance and constancy tests are of special importance. A set of parameters which has the largest impact on patient dose was identified and discussed during the EC Workshop "Technical and physical parameters for quality assurance in diagnostic radiology: limiting values and tolerances of the measuring methods", Brussels 1988.

Test objects and phantoms are important tools for checking the technical and physical parameters. They differ in design, purpose and output and will, by those various forms, make it difficult to harmonise quality control measures. Therefore, a dedicated workshop aimed at specifying design criteria of test objects and phantoms for monitoring the performance of radiological equipment and previously selected image quality criteria, including reference dose values, Würzburg 1992 (see also V.B.5).

Several operational parameters and applications of CT were assessed to identify the causes for the differences in patient exposure.

Automatic Exposure Control (AEC) Systems

The performance of the AEC systems in three makes of mammography X-ray equipment have been investigated. Radiation fields transmitted through perspex phantoms resembled closely those transmitted through breast material. It was found, however, that test objects of small diameter might allow more scattered radiation to influence more the AEC detector response. The manufacturers have been informed of this finding.

Film-Screen Combinations

It was shown that radiation qualities for the determination of the speed of film-screen combinations should closely match those reaching the film-screen combination after having passed through the patient and an anti-scatter grid. Since standards for speed classes of film-screen combinations are being prepared, this should be taken into account.

Anti-Scatter Grids

With a new optimisation modelling technique commercially available grids were compared and grid design was optimised for a wide range of imaging situations. Recommendations have been made for the choice of grids in a number of situations.

New Radiological Procedures

Radiation protection aspects, namely the possibilities of dose reduction were also studied for the newly developed digital imaging systems such as digital image intensifier radiography and photo stimulable storage phosphor systems. There are not yet clear conclusions on improved image quality and dose reduction. The need was stressed for an external audit of the effectiveness of image quality/patient dose. Standardised acceptance tests, write-off criteria and performance tests should be established. The use of storage phosphor systems in mammography was not

recommended, but a statement was elaborated on the perspectives of digitalization in mammography, mainly at the request of the CEC Programme "Europe Against Cancer" (see also V.B.5).

In some cases, diagnostics using ionising radiation can be replaced by methods involving less or no radiation exposure. The diagnostic value and patient exposure of examinations to detect heart muscle diseases or certain tumours, using nuclear medicine procedures such as immuno-scintigraphy with monoclonal antibodies, were compared with methods of conventional X-ray and ultrasound. However, it is extremely difficult to establish objective criteria for the diagnostic benefit of such examinations and to relate them satisfactorily to exposure data.

V.B.4. Evaluation of radiological practices

Several surveys were re-evaluated in the light of new insights, data treatment or updated enquiries so that data on frequency of examinations, number of films and the corresponding values for the genetically significant dose (GSD) and the effective dose equivalent per caput (EDE) could be updated. A more detailed analysis of the differences noted in surveys in France, Italy and the UK revealed some reasons for the differences in the values for GSD and EDE, which could, in part, be attributed to the justification of the diagnostic examinations, the radiological practices and the age distribution of the patients, as well as to the introduction of quality assurance programmes and the use of new technical means and procedures. Specific types of examinations were surveyed, eg mammography and intravenous urography. Consideration was given to specific patient groups such as paediatric radiology, or to new techniques such as computed tomography.

In five Member States, the evolution of the use of CT has been investigated. Conclusions are already available for the UK; while for France, Italy, Denmark and Portugal, intermediate results describe the trends and collective effective dose per caput of the population. Differences are explained by differences in makes of equipment, as well as in organisational, training and funding conditions.

These surveys provided a baseline of data against which the effects of quality assurance and dose reduction measures can be evaluated, besides detailed information on the state of technique, practice and exposure conditions. The repeated survey of intravenous urography in northeast Italy showed, for example, that five years after quality assurance measures were introduced, the EDE dropped from 0.091 mSv/year to 0.051 mSv/year as a result of fewer examinations performed (replacement by ultrasound), use of higher speed film-screen combinations and fewer exposures per examination.

Diagnostic algorithms and their impact on the dose to the patient have been investigated for specific diagnostic groups. Factors such as global health care organisation, "weight of opinion" of the referring clinician, his relation to the radiology department also have to be taken into account.

A comparison of practices in paediatric radiology showed enormous differences in patient dose for the same radiological examination, up to 1:186 for congenital hip

dysplasia in infants. The data collection in 10 European countries contributed to the establishment of guidance on reference doses for use in paediatric radiology.

V.B.5. Establishment of quality criteria of radiographic techniques, radiographic image and patient exposure

V.B.5.1. Quality Criteria for Adult Radiology

The need for more precise data on image quality related to patient exposure lead to the creation of a study group composed of contractors and some invited radiologists and radiographers. They elaborated a list of quality criteria for diagnostic radiographic images for typical projections of six conventional examinations: chest, skull, lumbar spine and lumbar-sacral junction, pelvis, urinary tract and breast; the quality criteria considered:

- "diagnostic requirements" defined by radiologists, enumerating the anatomical features which should be recognisable on the normal radiograph;

- "guidance to good image performance" describing the image details which should at least be detectable on the radiograph and giving a reference dose value which can be achieved when respecting sound radiographic technique;

- an "example for good radiographic technique" by which the items under the above paragraphs can be realised.

The quality criteria were tested on about 1,000 patients, by 25 radiological departments in 10 European countries and discussed and revised at a Workshop on "Optimisation of image quality and patient exposure in diagnostic radiology", Oxford, 1988. They were submitted for comments and improvement to national and regional professional associations or societies. Their contributions were considered in the 2nd edition of the Working Document on "Quality Criteria for Diagnostic Radiographic Images". This Working Document is now available in all official languages of the EC. It is an important step towards the establishment of comparable radiographs at reasonable doses to the patient.

Several contractors investigated problems encountered when these quality criteria were brought into practice. For instance, it was found to be difficult to define unambiguously speed classes of film-screen combinations for an optimal selection or to detect, as early as possible, a degradation of certain equipment and to introduce automatic corrective measures.

The more general applicability of these quality criteria was tested in the 1991-Trial with 3 examinations: chest, lumbar spine and breast, in which 83 radiological departments from 16 European countries participated. The doses were measured for more than 2,000 radiographs, the image quality of which was then rated by independent radiologists, assisted by medical physicists. The evaluation of these data will demonstrate if the conclusion of a similar Trial in paediatrics can be confirmed: that radiographs which fulfil most of the listed technical criteria come up with the lowest dose.

The 1991-trial pursued two more objectives:

- the use of the same set of quality criteria can provide a basis for producing comparable radiographs, which is of great actuality with a view to the Large European Internal Market;

- in addition, such a trial can stimulate the medical staff to look for further improvement of the radiological process and will indicate to manufacturers where equipment needs better and possibly more automated quality control and corrective interventions.

These measures can contribute to overall good practice in diagnostic radiology. They support the skill of radiographers and should be integrated into training programmes.

V.B.5.2. Quality Criteria for Paediatric Radiology

Since children differ considerably at the various developmental stages in body structure, tissue composition and organ functioning, it was necessary to establish a specific set of quality criteria for paediatric radiology. The corresponding study group developed the criteria based on a series of radiographs taken during some selected examinations of newborns, infants and children up to the age of 10. The dose measurements that accompanied the examinations came up with great variations of patient exposure, e.g. 1:43 for chest and 1:186 for congenital hip dysplasia were found. It was difficult to define reasonable dose ranges, since the available data are not yet conclusive.

The Working Document on Quality Criteria for Diagnostic Images in Paediatric Radiology was circulated for comments to professional individuals and associations in all Member States. The analysis of the answers will contribute to complete this document and introduce its implementation on a larger scale.

V.B.6 Knowledge Based Systems

Quality control testing of the radiological equipment deserves both the good functioning of the equipment and the reasonable exposure of the patient. Therefore, malfunctioning of the equipment must be recognised and remedial action taken as rapidly as possible. The wealth of data established in this field can contribute efficiently to good radiological practice in the form of knowledge based systems (KBS). While one project was developing the appropriate KBS, three other projects were developing and selecting the data for its use. As a first approach, the KBS was conceived for use in mammography. The development of a set of "pure data" has been started, whose results can be directly related to any changes in radiographic conditions. A serious co-operative effort will still be necessary in order to fulfil the promise of this new tool for immediate quality control intervention.

V.B.7. Cooperative Efforts

Beside this, the CEC VALUE - Programme for the dissemination and utilisation of scientific and technological research results, supported the elaboration of a catalogue for specific educational objectives in radiation protection for personal working with diagnostic radiological equipment. This catalogue will be translated into several official languages and may become a reference document for the respective training programmes.

The research results of the Radiation Protection Actions could also be implemented by co-operation with the European Community Programme on Europe Against Cancer - Breast Cancer Screening: The Study Group on Quality Criteria in Mammography elaborated a European Protocol for the quality control of the technical aspects of Mammography screening, which has been added to the European Guidelines for Quality Assurance of Mammography Screening. This document of the EC Europe Against Cancer Programme is available in the nine official languages and will be distributed widely.

V.C. CONCLUSIONS AND PERSPECTIVES

Optimisation of radiation protection in the reduction of patient exposure in medicine, and specifically diagnostic radiology, is a task which the Radiation Protection Programme has started successfully in some areas of radiology. In particular, quality criteria have so far only been established for some key procedures whereas many other important areas, e.g. paediatric radiology, CT and digital radiology, nuclear medicine, application of radiopharmaceutics, still need special attention. These efforts are particularly urgent in view of the rapidly expanding application of some of these procedures, the still largely unexplored potential in dose saving that can be achieved by them and, finally, the economic savings and better health care that can be provided by improved quality of diagnostic radiology.

In dental radiology, dose-reducing measures are most efficiently made by quality control of the technical parameters of the imaging process, including film processing. No specific research projects existed in the period considered since the requirements for good radiological practice in diagnostic radiology are equally valid. A training course on radiation protection principles in dentistry was organised by the CEC services.

Co-ordination between research institutes and clinics in different Member States and with other countries as well as training of all staff involved, are the most appropriate means for developing and bringing into everyday practice the achievements in dose reduction related to quality improvements. This is greatly aided by the new structure of multinational contracts and by the co-ordinated research programme that the Commission is implementing together with the IAEA in this area.

As a consequence of the new ICRP recommendations (1990), a revision of the EC Directive laying down basic measures for the radiation protection of persons undergoing medical examination or treatment is planned. The research action shall

contribute to the scientific basis for this updating. Emphasis should therefore be placed on the development of optimisation strategies. This requires comparable investigations, experiences and know-how, which will then enable measurement of improvement, audits, harmonisation, standardisation and risk assessment. The Commission's initiatives can define and pursue the necessary research lines, and co-ordinate them for data acquisition and evaluation. This will allow the Member States to advance in the implementation of radiation protection and allow the Commission's services to evaluate the efficiency of its research programmes.

VI. EDUCATION AND TRAINING IN RADIATION PROTECTION

VI.A. INTRODUCTION

The Radiation Protection Research and Training Programme 1990 - 1994 is responding to the recommendation of the Evaluation Panel, which had stressed that it was of utmost urgency to fund training programmes to ensure:

1. Continuity of existing knowledge, which has been carefully built up over a period of years by a selected but still relatively small community of scientists;

2. The background to pursue research avenues that will advance knowledge in the last decade of this century and into the next century;

3. The availability of up-to-date knowledge and well trained scientific an medical specialists for advice in the case of accidents such as that at Chernobyl.

Furthermore, the Council decisions for the 1990-1991 and 1992-1993 periods specified that it was necessary to encourage training of research workers and engineers and that advanced training was essential for radiation protection.

Education and training activities have been promoted by the Commission's services in charge of Radiation Protection: DG XI, DG XII and, where appropriate, the services of EURO-Courses of the Joint Research Centre at Ispra. These activities are grouped under the acronym ERPET (European Radiation Protection Education and Training) and involve:

- organisation of training courses;
- development and provision of information and training packages;
- exchange of scientists and promotion of participation in scientific conferences.

VI.B. ACHIEVEMENTS

During the 1990-1992 period, some twenty training courses, attended by about 600 participants, have been organised together with contractors or European scientific organisations. These initiatives covered wide ranging subject areas such as optimisation of radiation protection of the workers, the public and the patient, radiation physics, radioecology, management of nuclear emergencies, the use of the probabilistic accident consequence code COSYMA, modern techniques in radiation cytology and DNA repair, a.o.

Several courses have been updated and repeated in order to satisfy the demand, e.g. "the optimisation of technological protection in the design and operation of nuclear and industrial facilities" has been conducted four times. Other courses have stimulated interest on a national basis and have been repeated without further financial support from the Commission, e.g. "quality assurance in diagnostic

radiology, image quality and dose reduction". A more consistent support in training in radiobiology has been recommended. An enquiry about the present status of training in that field in the Member States has been carried out in order to establish the appropriate framework for such training.

Special attention is given to the evaluation of the ERPET activities. The same questionnaires (in 9 languages) were used for the evaluation by the course participants. The collected comments and criticism helped to refine the guidelines to the course organisers and the lecturers.

During the 1990-1992 period, 48 scientists were supported to allow their attendance of courses and scientific meetings, 9 postgraduates were awarded grants for specific scientific projects. A number of education and training concepts and programmes have been elaborated, partly with the support of the CEC VALUE Programme (Valorisation and Utilisation for Europe - Dissemination of Results). Audio-visual information material has been prepared to be used for the training of students, workers and medical staff.

The Training Committee met about three times a year to analyze the situation, to discuss new proposals and to advise organisational and structural improvements.

VI.C. CONCLUSIONS AND PERSPECTIVES

The efforts for harmonising education and training initiatives in the Member States must continue in order to assist professionals and students from different background levels to gain access to the most advanced knowledge and practice in radiation protection. These efforts should be coherent with similar efforts by other international bodies.

In the framework of the planned cooperative approach to Education and Training in radiation protection by the participating international organisations: WHO, IAEA, ILO, PAHO and the CEC, the following main lines have been defined:

1. Establishment of common objectives and programmes for education and training;
2. Definition of the principle character of training courses in the European context;
3. Elaboration of guidelines and reference documents for education and training of the various professional groups involved in radiation protection measures, surveillance and interventions. It will be important to take into account the educational levels, teaching and training conditions, as well as implementation possibilities;
4. Cooperation with and assistance to accreditation bodies and procedures, concerning the definition of professional bodies, teaching and training programmes, certification.

The possibility of delivering a certificate which has European-wide recognition is to be studied.

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The present document aims to:

(i) present the evolution of the radiation protection programme during the period 1987-92.

During these six years the programme has continued to investigate in a comprehensive way the complex problems of radiological protection research. The scientific contents of the programme have been systematically adapted to the needs and priorities of improving radiological protection with the aim of providing a sound fundamental base for the support of the regulatory activities of the Commission. The programme has made use of multidisciplinary research with the long-term goal of assessing accurately low-dose radiation risks. Research contractors working in several areas of the programme are recognized as leaders in their fields and the programme is acknowledged as playing an important role in radiation protection worldwide. A very good balance has been achieved both in and between the different subject areas of the programme;

(ii) give an overview of the progress made during the period 1987-92, including through the implementation of post-Chernobyl actions made possible by the 1988-89 revision of the research programme.

One important change in this period was the decision to manage the programme using multinational, multipartner contracts from 1990. This change has proved highly successful, has been welcomed by the contractors and has led to a further integration of research between scientists working in the same field.

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